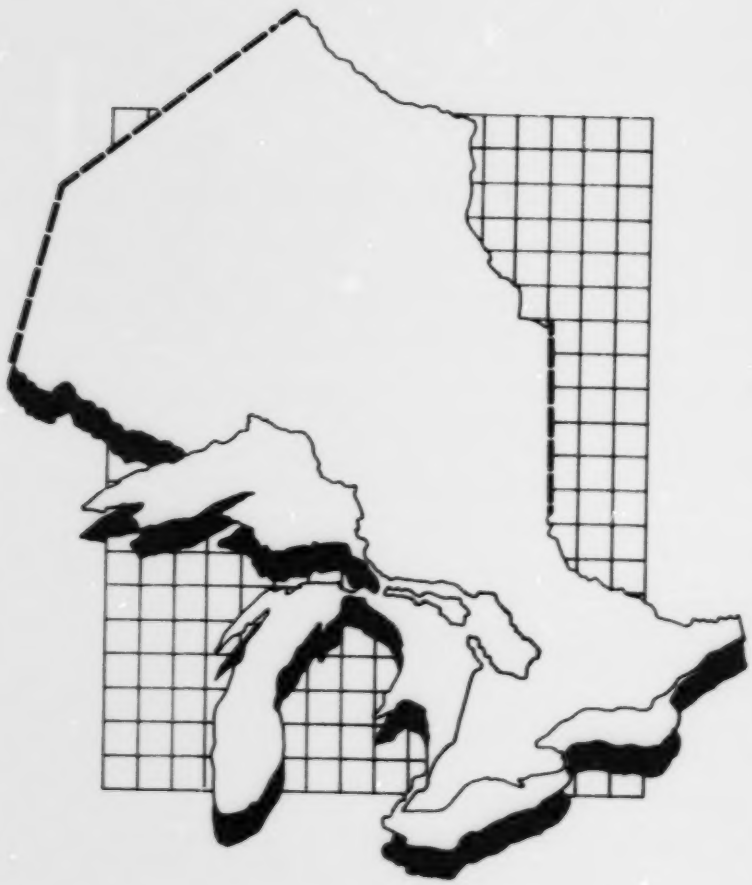
# Solar Energy and Land Use



Ministry of Energy
Ontario

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# SOLAR ENERGY

# AND

# LAND USE

a discussion paper prepared for the
Ontario Ministry of Energy
by
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# SOLAR ENERGY AND LAND USE

## Executive Summary

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The sun is the source of an inexhaustible, low intensity, and highly variable form of radiant energy. To be utilized, this radiation must be converted to a useful energy form such as heat, electricity or chemicals.

Thermal systems, which convert solar energy to heat, represent the most extensive applications of solar energy developed so far. There are two major system types: passive, using building components to collect, store, and distribute energy for space heating, primarily in residential applications; and active, using mechanical components distinct from the building structure. There are a number of approaches to passive solar design, most of which are cost-effective when combined with measures for energy conservation. Active systems can be used in applications of varying complexity, ranging from water pre-heat (direct use), domestic hot water (DHW) with storage; DHW and space heating with storage; and space heating and cooling. Water pre-heat direct use applications are presently cost-effective for a number of commercial, industrial, and residential projects.

Solar electrical "photovoltaic" technology is rapidly evolving and may find application in remote areas for installations with low power requirements. A reduction in generating costs by an order of magnitude appears feasible in the near future, making photovoltaic power competitive with a number of other sources. When this happens, it may result in much wider applications and numerous installations in urban areas.

Solar chemical processes are still in a research and experimental stage, with no applications in sight at the present time.

Solar thermal systems are of the greatest concern to municipal planners. Different building types have varying needs for solar assisted space heating and hot water heating. Residential and public buildings show the greatest potential to use both; while hospitals, hotels, schools, some industries, and a few other building types have substantial hot water demands which may be partially served by solar systems.

The land use impacts of solar systems are primarily related to the type of solar access that a building type requires (site, south wall, or roof) and the kind of shadows cast by building + collectors, which dictate how far apart buildings must be spaced to preserve solar access. Shadow impacts also vary with topography, vegetation, latitude, and climate, and have differing importance depending on whether one is dealing with an existing neighbourhood or new development area. Existing residential neighbourhoods have a varying ability to use solar access, while new neighbourhoods can usually be planned comprehensively for complete solar access. Other land uses and building types can generally use and

accommodate roof-mounted solar collectors, although their integration with historic building types may present difficulties.

In developing a strategy to incorporate solar potential into the planning process, municipal planners must balance considerations of process (political acceptance, administrative costs, legislative flexibility), solar access (definition, impacts, standards, and protection), and flexibility (to accommodate changing technologies, climate, and development potential). The tools available to implement solar access range from the general (Official Plan), to development area controls (zoning, subdivision plans and agreements), to the site-specific (site plan controls, easements, and covenants). Each tool has an important, but limited role in the development approvals process, and usually must be combined with other instruments to achieve solar access, as well as other, community objectives.

# SOLAR ENERGY AND LAND USE

A Discussion Paper

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## Purpose

The purpose of this report is to provide municipal planners in Ontario with an understanding of solar energy, how it is being utilized in buildings and industries by technologies and processes currently available, and how it may be utilized in the future. The report discusses what effects solar technologies may have on building design and land use, and what responses could be developed in the area of land use planning and development controls to accommodate these technologies.

Chapter 1 discusses the essential characteristics of solar energy, how it can be utilized, and the basic components of a solar energy utilization system. In Chapter 2, the three processes for converting solar radiation into useful energy are discussed in detail: solar thermal (passive and active systems), solar electrical, and solar chemical processes, together with applications, case studies, and cost-effectiveness (particularly for solar thermal processes, the most developed of the three).

Chapter 3 concentrates on the application of solar thermal systems for space heating and hot water heating to different building types. This is summarized in a table of the applicability of solar energy to these building types in Ontario. Chapter 4 discusses the land use impacts of accommodating solar systems in built-up and new development areas for each land use/building type. Chapter 5 concludes by outlining in general terms, the legislative and other tools available to planners in Ontario for implementing solar access.

## 1. CHARACTERISTICS OF SOLAR ENERGY

The sun is an enormous, inexhaustible, and free energy resource. As well, many of the non-renewable and expensive energy sources we so conveniently use, such as natural gas, oil, and coal, are in fact forms of stored solar energy.

Energy from the sun itself is a resource with complex characteristics. The total amount of energy available is very great - the annual radiation falling on a Toronto house may be 2 to 5 times the total energy demand of the house and its occupants. However, in order to make effective use of this energy, we must recognize its characteristics:

- it is low in intensity, requiring large collectors when large amounts of energy are needed;
- it is subject to unpredictable interruptions from clouds, rain, snow, hail, or dust;
- it is available only during the day, and varies with the seasons and time of day.

Solar energy approaches the earth as electromagnetic radiation, ranging from X-rays only 0.1 $\mu$m * in wavelength, to radio waves over 100 m in wavelength. More than 99% of this energy is in the short wavelength band, comprising approximately 9% ultra-violet radiation, 40% visible light, and 51% infrared radiation. (Figure 1)

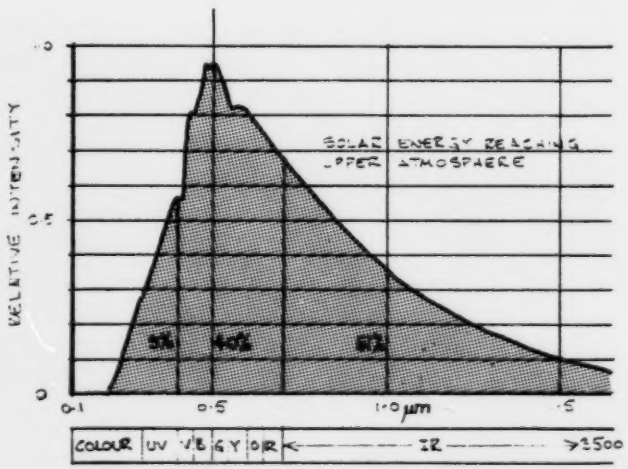



Figure 1: Wave Length Distribution of Solar Energy

* $\mu$m = millionths of a metre

The sun emits this radiant energy at the incredible rate of $4 \times 10^{23}$ kW. Even though the earth is a small body more than 150 000 000 km from the sun, and only receives a small portion of this radiation, the quantities of energy reaching the earth are still enormous. The most populated parts of Ontario receive more than 3.5 to 4 $kW/m^2$ each day, averaged over the entire year. This is a favourable value compared to many other parts of the world, where weather conditions interrupt radiation.

Solar radiation varies with the latitude of a location and the time of day. In Ontario, most solar energy is received during the summer and less during the winter; a seasonal variation which increases as one goes farther north, to higher latitudes. Also important are the daily variations in solar energy - rising to a maximum at noon, declining towards sunset.

For certain applications such as space heating, these seasonal and daily variations in energy level may be difficult to match to end use requirements, necessitating some form of energy storage to make the most effective use of the energy collected. (Figures 2 and 3)

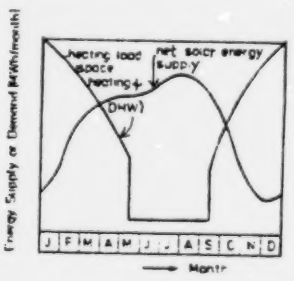



Figure 2: Annual Variation in Solar Energy Supply and Energy Demands

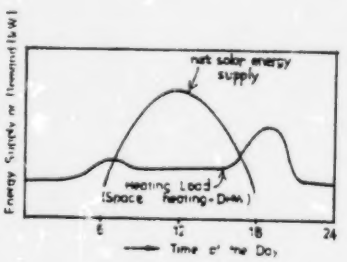



Figure 3: Daily Variation in Solar Energy Supply and Energy Demands

For other applications such as pre-heating water for industrial processes, solar energy may be used directly, without storage.

In order to be utilized, solar radiation must be converted to an energy form required by the end use. Depending on the application, this will be one of three processes:

- Thermal: the conversion of solar energy to heat. This process is used in active and passive solar heating systems, and is the principal application of solar energy at the present time.
- Electrical: the conversion of solar energy to electricity. This will be an emerging area of technology and applications over the next decade.

- Chemical: the utilization of solar energy to produce chemicals. An example of this process is photosynthesis, the most important process in nature, by which plants produce food and convert carbon dioxide to oxygen. Research and experimentation in this area is just beginning.

There are several functions to most systems which utilize solar energy:

- Collection of solar energy
- Transformation of the collected energy to another usable form such as heat or electricity
- Transfer of the usable energy form to the point of use.

If the transformed solar energy cannot be used immediately, it may be transferred to a storage device to retain it until required by the point of use. These processes are illustrated in Figure 4.

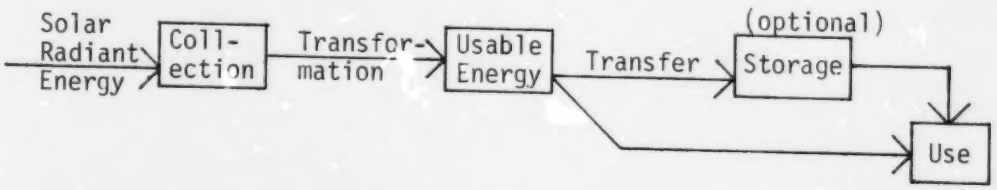



Figure 4: Solar Utilization System

Depending on the particular application, solar systems differ in the actual materials and components which perform these functions. Although in abstract terms, the functions are similar in each case, solar systems are not dominated by a single concept or technology. Rather, there exists a wide variety of different approaches, each one tailored to the needs of a specific application or climate.

# 2. SOLAR SYSTEMS

Solar systems are the collections of components by which solar energy is processed (received, converted, and ultimately utilized) in an application. As discussed, three processes are possible: thermal, electrical, and chemical.

## 2.1 Thermal (Heating) Processes

Thermal systems, which convert solar energy to heat, represent the most extensive applications of solar energy developed so far. A number of systems have evolved over the last decade for purposes such as space heating, heating of domestic hot water, preheating of hot water for industrial purposes, and swimming pool heating.

There are two major kinds of solar thermal systems:

- Passive systems use the structural and architectural elements of the building to collect, store, and distribute thermal energy for space heating.

- Active systems use a set of specifically fabricated components for space or water heating, distinct from the building structure, but attached to, or near, the building or use served.

### 2.1 (a) Passive Solar Systems

In a passive solar system, the structural and architectural elements of a building (walls, floors, windows, etc.) are used to collect, store, and distribute thermal energy for space heating, as well as performing their principal functions in the building fabric. The major application of passive solar design has been in residential buildings, although some industrial, commercial, and public buildings can be passive solar heated, in whole or in part.

Passive solar design is a supplement to energy conservation techniques in building, by carefully designing buildings to maximize the amount of solar energy absorbed in winter, and in summer, to minimize the heat absorbed, while maximizing convective cooling. A simple passive system uses no fans, pumps, or mechanical assist devices. Thermal energy moves by natural processes (conduction, convection, and radiation). "Hybrid" passive systems utilize low horsepower fans or blowers to increase the convection or mass flow of the system. Failure of such mechanical assist devices will not cause any harm, but will only reduce the efficiency of the system.

In a passive system, the collector is usually south-facing glass, also used to transmit light into the interior of the building. In winter, when it is most needed, the south wall receives the most solar radiation of any building face. The key to glass as a collector material is that it transmits as much as 90% of the incoming short-wave radiation (under 1.5μm wavelength) but is opaque to the long-wave (heat) radiation (greater than 4.5 μm wavelength) emitted by absorption materials inside the building (Figure 5). Therefore, the collector acts as a heat trap, the so-called "greenhouse" effect.

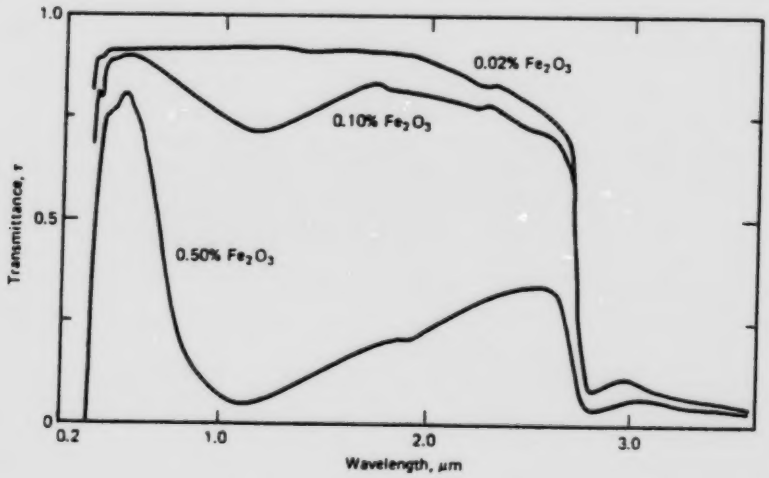



Figure 5: Spectral Transmittance of 6 mm Glass, with Various Iron Oxide Contents.

The transformation of solar radiation to useable thermal energy is done by building components with high heat retention or "thermal" mass, such as concrete floors, masonry walls, or devices such as water containers. The same elements also act as thermal storage masses. Alternatively, in a hybrid system, heated air may be conveyed to storage tanks of rocks, water, or phase-change materials. Heat transfer from storage to the point of use can be by conduction from thermal mass materials, and natural or fan-assisted convective air flows.

Additional costs for passive systems tend to be, and should be, low, because in the "pure" passive case, only re-arrangement or substitution of building components which must be in place anyway, is involved, rather than a complex system of piping and controls additional to the building components (as in active systems).

• Approaches to Passive Solar Design

There are a number of generic approaches to passive solar design, each of which has specific components and heat delivery characteristics. They may be used alone or mixed together, depending on building program and heating requirements.

- Direct Gain

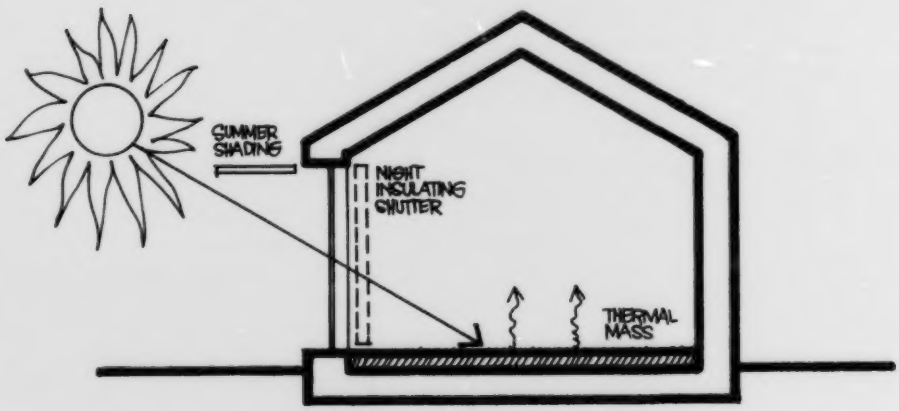



Figure 6

Direct Gain is the most frequently used passive solar heating method. Sunlight enters the building through large areas of south-facing glass and thermal energy is stored within habitable spaces in thermal mass areas such as floors and wall (insulated on the exterior to minimize heat losses). To cut down on heat losses through the glass at night, some form of window insulation, such as insulating shutters, drapes, etc. is essential.

Solar gain is desirable in winter, but undesirable in summer. Vertical glass with a due south orientation is preferred because it receives the greatest amount of winter radiation when sun angles are low, and the least amount of summer radiation when sun angles are high, in comparison with east or west wall orientations. External shading devices (roof overhangs, trellises, etc.) may still be necessary to block summer heat gains. Movable shading devices such as blinds are also useful to prevent overheating during intermediate seasons and mild weather.

Advantages include low capital costs - if the glass area of a building is not increased (but only relocated predominantly to the south), then the only additional costs need be those of the thermal mass materials; thermal mass materials aid summer cooling; large glass areas provide large amounts of natural light; and excellent potential for retrofitting existing buildings.

Disadvantages include thermal stratification - heat tends to rise by convection to the top of a building or room, unless air flow is assisted by mechanical means; floor coverings, drapes, furniture, etc. can fade in direct sunlight; large variations in indoor temperature can occur; and large glass areas may cause lack of privacy.

- Indirect Gain - Thermal Storage Wall

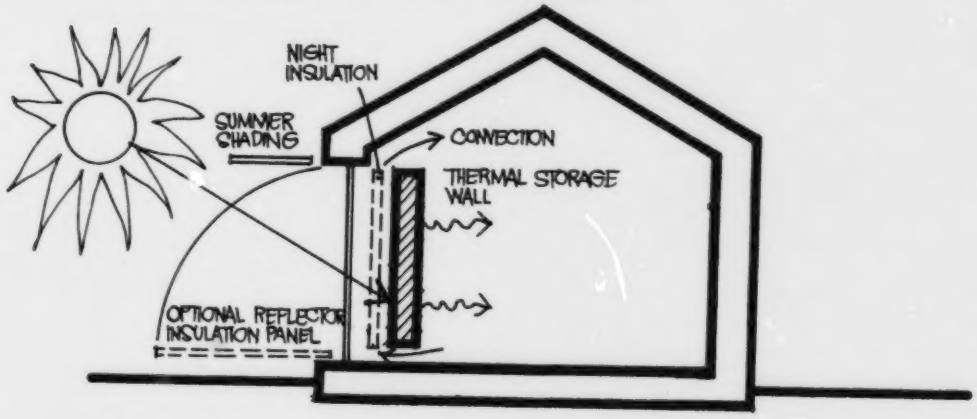



Figure 7

This method modifies the Direct Gain approach by placing a mass wall immediately behind the south glazing in order to make maximum use of heat gain, and reduce the large temperature swings from day to night. The thermal storage wall can be made of any material with high heat absorption and retention, such as thick, dark-coloured concrete, solid masonry, and water containers. (Water has a higher heat storage capacity than masonry materials). Openings at the top and bottom of the wall allow convective air flow to improve performance, and to provide quicker heating up of the interior spaces in the morning.

The effectiveness of this approach may be reduced unless the south-facing glass is protected at night. A hinged insulating reflector may be possible for this purpose. As with direct gain, some external shading devices may be necessary to prevent excessive heat gains.

Advantages include the combination of radiant and convective heat which results in better thermal comfort and lower temperature swings than the Direct Gain approach; moderate additional cost over conventional construction (primarily thermal storage wall and window insulation); and summer cooling, aided by ventilation caused by the thermal mass together with exterior vents.

Disadvantages include thermal stratification unless air flow is modified by mechanical means; reduced exterior view and daylight from the opaque storage wall, meaning that other, less desirable building faces

may also have to be used for glazing; retrofit applications are limited because of the weight of the thermal storage wall; and temperature swings within habitable spaces are large (8°C/day).

- Isolated Gain - Attached Sunspace

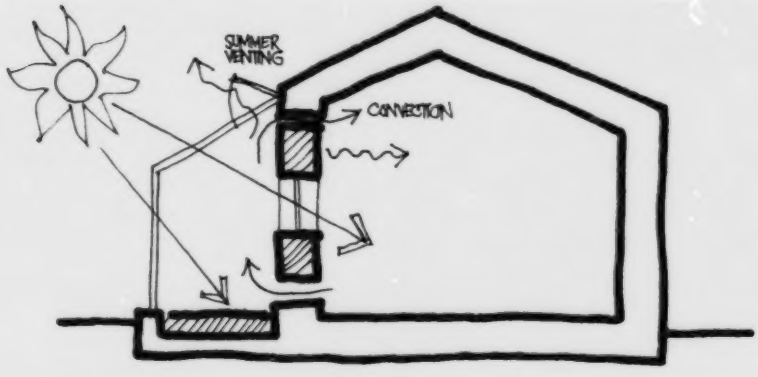



Figure 8

A variation and combination of the Direct Gain and Mass Storage Wall approaches, the Attached Sunspace separates the south-facing glass wall from the mass thermal wall. The living space gets heat through direct gain, and by conduction at night through the mass wall. The sunspace is often left unheated (except by the sun), and is subject to large temperature swings. However, it also tends to buffer the main living space from these swings, in contrast to the direct gain method. The sunspace also provides additional floor area for growing plants, but due to temperature differences, is not always habitable in winter.

This approach has several advantages: it provides a desirable combination of radiant and convective heat, as in the mass storage wall approach; it has good potential for add-on retrofit applications; it cuts down on air infiltration into the building, by providing an unheated air buffer to the south; it can provide summer cooling by inducing an internal convective air flow, if vented at the top of the sunspace; and the sunspace is aesthetically attractive, as well as adding livable area to the building.

Principal disadvantages include expense - additional floor area with a large glazed area is added to the building, the fact that large temperature swings cut down on livability at certain times of the day or year; difficulties in insulation; the requirement for an open plan within the building to facilitate air movement; and the requirement for venting and isolation of the space from the main living areas in order to avoid summer overheating.

- Attached Sunspace with Remote Thermal Mass

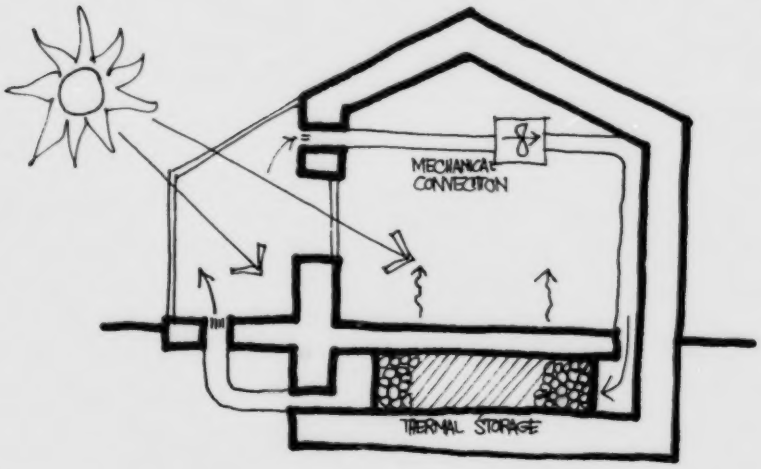



Figure 9

This concept is a "hybrid" system which combines the attached sunspace approach with mechanical convection of excess heat to an insulated, remote thermal storage system, as in active systems. This greatly increases the usable amount of thermal energy available for use in sunless periods. It also provides lower temperature swings in the habitable spaces of the building, as well as greater efficiency and more precise, thermostatically controlled conveyance of heat to these spaces when needed, in comparison with other passive approaches.

The advantages of this approach are similar to those for the Isolated Gain - Attached Sunspace approach but with greater efficiency in the use of stored thermal energy.

Its disadvantages are that it is more expensive than the unassisted Isolated Gain approach, not only in the substantial costs of the attached sunspace, but also in costs for thermal storage under the principal living areas, and operating and maintenance costs for blowers and controls. Large variations in sunspace temperature can also reduce its livability; and retrofit applications are limited because of the substantial thermal storage bin required in the basement.

- Thermosiphon with Thermal Storage

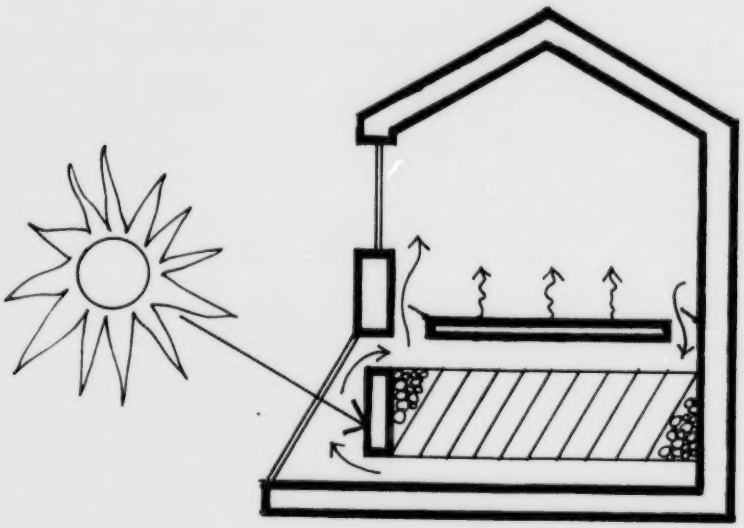


Figure 10

In this concept, the Indirect Gain - Thermal Storage Wall is removed to an area immediately below the habitable spaces of the building. Thermal storage can consist of pebbles or crushed rock in bins, or water tanks. Mechanical fans are desirable to convey stored heat to the habitable areas above.

The separation of solar collection and storage from the habitable spaces of the building means that fairly conventional interior plans are possible. The storage provides both a radiant and a convective heat source, as well as summer cooling by ventilation. The thermal mass volume can be made as large as necessary, and the concept is adaptable to south sloping sites.

Disadvantages include additional expense compared with other concepts, lack of adaptability to retrofit applications, and an additional ½ to 1 complete storey. There are large variations in the sunspace temperature, but this is of little consequence, since the area is below habitable spaces.

- Double Envelope

Double envelope buildings are super-insulated, with an air circulation space provided around all habitable areas, separating them from the external wall. This air circulation space, essentially the entire roof and north wall of the building, is exposed to the earth, making use of it for thermal storage, and making use of available heat or cold for tempering the internal environment of the house.

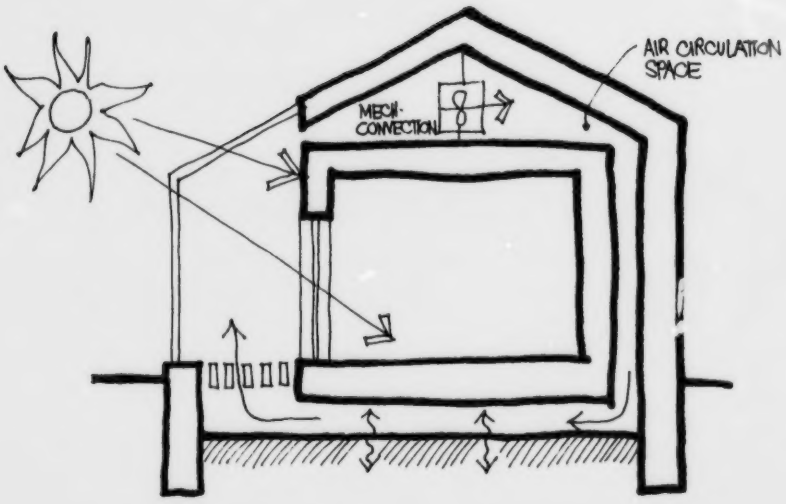



Figure 11

In theory, the double envelope building makes use of the storage capacity of the earth, and provides an air buffer to the habitable spaces, thereby reducing their heat losses to the exterior. The actual performance of these buildngs, however, is a source of some controversy, which is not surprising, since the first prototype was only constructed in the U.S.A. in 1978. The benefits of the air space to reduce infiltration losses are well accepted. However, the temperatures in this circulation space are often higher than the internal temperature, resulting in substantial heat losses to the exterior, and therefore, poor utilization of excess heat from the sunspace. The benefits of earth contact as a storage medium are also not easily quantified, but its efficiency is thought by some experts to be as low as 10%. Other disadvantages include complexity and high costs of construction, lack of potential for retrofit, and other liabilities of earth contact such as moisture and insects.

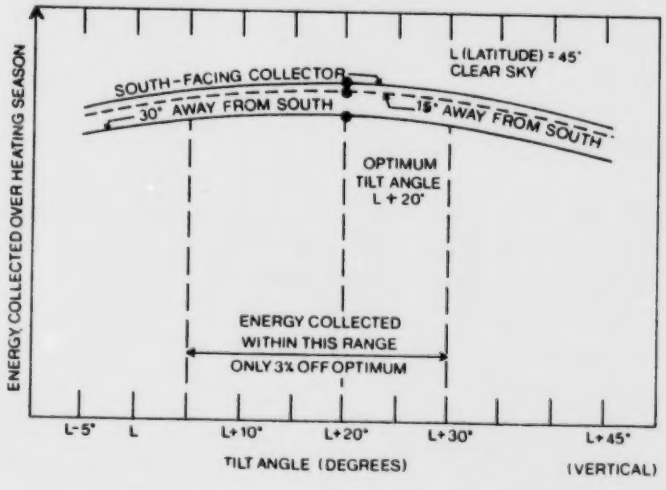
- Performance of Passive System Components

- Collectors:

The "collector" in a passive system is generally a south-facing glass wall or greenhouse. Since passive systems are intended to collect heat only for space conditioning in the winter, the optimal tilt and orientation of this wall must be designed for winter conditions, when sun angles are low.

The ideal tilt angle for the collector is fairly steep: Latitude angle + $20^{o}$ (for example, in southern Ontario, this would result in $44^{o}$ Latitude angle + $20^{o}$ = $64^{o}$). A tilt angle of up to Latitude angle + $30^{o}$ (i.e. $75^{o}$ $\pm$ in southern Ontario) also results in energy collection close to optimal. (Figure 12).

The National Research Council of Canada has examined the effect of different angles of tilt and orientation. Fig. indicates that over the *winter heating season* the energy collected is maximized for a collector facing due south and tilted at an angle from the horizontal of 20° greater than the latitude. There is very little loss in the amount of energy collected with a tilt of between 5° and 30° more than the latitude and orientations 30° away from due south.




VARIATION OF SEASONAL ENERGY COLLECTED WITH TILT ANGLE AND ORIENTATION

Source: National Research Council of Canada Building Research Note. Note No. 104, December 1975

Figure 12

Since vertical glazing has fewer problems in jointing, flashing, and rain protection than angled glazing, many designers use vertical glazing in passive systems, accepting a slightly less than optimal energy collection performance. This can be compensated for by slightly larger glass areas.

Ideally, glass areas should be oriented to face due south. Deviations of up to 15° from due south result in only minor losses in performance. However, the combined effects of less than optimal tilt angle and less than optimal orientation must be considered, and may result in the need for large glass areas in order to supply the design heat gain.

Large glass areas will lose heat at night in the winter unless they are insulated. A further advantage of vertical glazing is that it is relatively easier to insulate than sloping glass. Under Ontario's climatic conditions, the importance of night insulation cannot be overstressed: the heat loss from south facing glass at night may be equivalent to the heat gain received in the day, unless insulation is provided.

Passive systems operate year round, potentially receiving more energy

in the summer, when the sun shines for longer hours (although at a steeper angle than in the winter). This extra energy can be a problem in the summer, as well as fall and spring seasons, when space heating needs are reduced, or not required at all.

A further advantage of vertical south-facing glass is that the summer sun angle is steepest, resulting in less heat build-up from south glass than glass facing in other directions such as east or west; and less heat build-up from vertical glass than glass tilted more towards the sun.

Even with vertical glass, external shading devices may be required to block excessive heat gains, as well as vents or other methods to dump excess heat from building up in the system, and in building spaces.

- Transfer and Control

Simple passive systems rely on conduction and radiation from thermal mass materials within the building. These processes are difficult to control, and may have other side effects such as air stratification, which results because hot air rises to the top of the building. Other side effects due to this lack of control include the overheating of room spaces. This must be controlled by blocking the sun before it gets into the building.

The performance of passive transfer systems can generally be improved by mechanical devices such as fans and vents to improve air flow, de-stratifying air, and directing it to locations in the building where it is needed. Such devices can also be used to automatically dump or discharge excess heat when it is created within the building. Failure of these devices may result in temporary discomfort to the occupants under certain conditions.

- Thermal Storage

In simple passive systems, thermal storage generally consists of components of the building itself. To have effective thermal mass, they also have density, and therefore, weight. Unless located at or near ground level, thermal storage components will require extra support. Certain components are self-supporting such as walls; others, such as water or rocks, must be held in containers and supported by foundations or structure.

Thermal storage in contact with the ground needs proper insulation to avoid heat loss to it. Even with insulation, this heat loss will be slowed, but not stopped altogether. Insulation also has a role in retaining the heat for night time use (making the thermal storage available once again for heat gain during the following day).

Passive Solar Systems

Case Study - Single Family House, Dira Construction Ltd., Guelph

This 169 $m^2$ single family house was one of five built by Dira Construction Ltd. under the Ontario Hydro Passive Solar Program in 1981. Under this program, each builder selected was required to design and build five houses which used only 5 kWh/$ft^2$ for space heating annually. Hydro financed each house up to $7,000, of which $5,000 covered incremental construction costs.

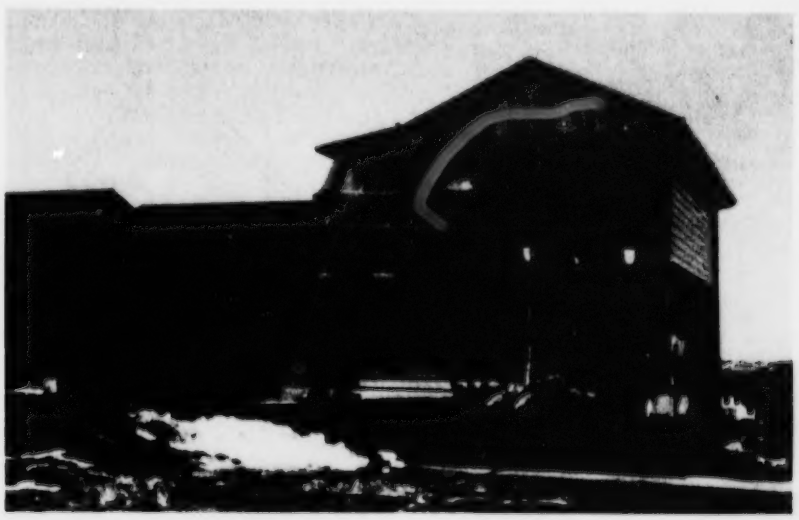
Passive Solar Components: The primary consideration in construction was energy efficiency - achieved through added insulation, control of air infiltration and exfiltration, and casement or awning windows, rather than types that need clearance to slide and cannot be made airtight. In addition, the homes feature glass areas positioned to capture maximum heat from the low rising winter sun and to avoid excessive heat gain from the higher rising summer sun; insulating curtains; internal masonry and concrete under the flooring in areas where the winter sun strikes inside the house, to create added thermal mass.

Costs: Additional labour, special materials, upgraded materials and extras required to make the house conform to Ontario Hydro criteria came to $6,609 (1981). However, $1,026 was for insulating curtains in the solarium and large south facing window area. When the costs of regular curtains are deducted, the extra costs total $6,000.

Fuel units saved (estimate) = 48.2 GJ

Capital Costs: $/GJ = $124.48 (1981)

(GJ = Giga Joule, a measure of energy
1 GJ = 1 billion joules
= 9,478 BTU (British Thermal Units)
= 277.7 kWh)



Source: Ontario Hydro

Passive Solar Systems

Case Study - Single Family House, John Boddy Developments
Scarborough, Ontario

This house is a winning design in the 1980-81 Ministry of Energy-sponsored, HUDAC-administered Passive Solar Housing Competition. The house has 2 storeys, with 158 $m^2$ of living area, and is set on a north-south axis. An attached sunspace at the rear (south of the home) is overlooked by a balcony off the master bedroom. Upper and lower floors are connected by full-stacking, sliding glass doors that open into the living space.

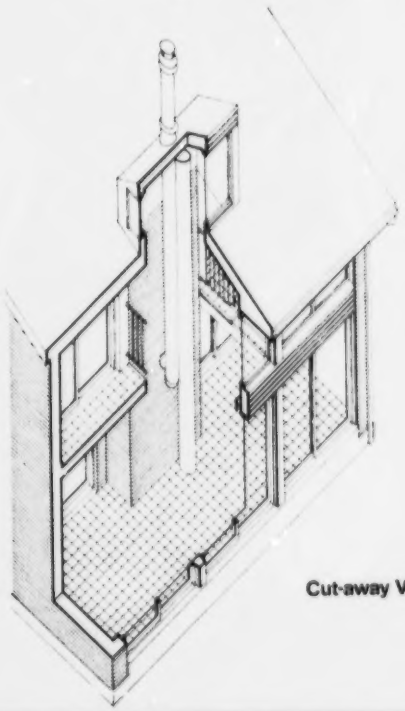
Passive Solar Heating: The heating system incorporates direct solar gain from a south-facing sunspace which adjoins the main living quarters. A concrete slab floor with quarry tile absorbs the excess heat, and as it cools, the heat is radiated through the rest of the living area. Added thermal mass is provided by a masonry fireplace wall, and drywall. To alleviate possible temperature swings, return air registers are located at ceiling level to distribute heat to other living spaces. This is achieved through a furnace ventilation system, using a continuous operation fan.

Costs: System incremental cost, excluding thermal blinds = $9,500

Energy collected = 79.1 GJ

Fuel units saved (assuming 95% efficient furnace) = 83.2 GJ

Capital Costs: $/GJ = $114.18 (1981)



Cut-away View of Sunroom

Any thermal storage has a limited capacity to accept heat, beyond which it must be dumped to the exterior. Otherwise interior temperatures will rise beyond comfort levels.

• Cost Effectiveness

It is relatively difficult to assess the cost-effectiveness of passive solar designs because there is rarely a test case against which to compare. Passive solar designs are often custom, "one-off" buildings, and passive solar components are integral to the building construction, making it hard to separate out cost components. However, two demonstration projects conducted recently in Ontario have allowed costs and benefits to be assessed fairly accurately.

The 1980 Ministry of Energy/HUDAC Passive Solar Demonstration funded 14 builders across the province to construct passive solar single family homes as modifications of existing house designs. Therefore, a conventional house plan was also available in each case for comparison. The conclusions from the project were that passive solar designs should be incorporated into homes that are energy-efficient in overall terms - for example, an energy-efficient house with passive solar heating was able to save over 60% in heating costs compared with a conventional house; while the use of passive solar systems alone seldom resulted in savings of more than 25%.

Therefore, builders incorporated a number of features to reduce energy consumption, including improved insulation and vapour barriers, reduced glazing to the north, east, and west, vestibule airlock, improved doors and windows. The average results from the project were as follows:

| | All 14 Houses | 11 Houses, without high & low values |
|---|---|---|
| Energy savings in kWh | 16,575 | 17,311 |
| Energy savings in GJ | 59.67 | 62.32 |
| Capital costs of energy conservation and passive solar features | $6,616.03 | $7,469.36 |
| 1981 capital $/GJ saved | $110.88 | $119.85 |

This last figure relates the dollars invested in extra construction costs to the amount of energy saved in GJ, over the comparison house.

Similar results were achieved in the 1981 Ontario Hydro Passive Solar Home Demonstration Program, one project of which is described in Case Study 1. A representative house from this program achieved the following results:

| | |
|---|---|
| Energy savings in kWh | 13,400 |
| Energy savings in GJ | 48.24 |
| Capital costs of energy conservation & passive solar features | $6,000.00 |
| 1981 capital $/GJ saved | $124.38 |

Cost trends in passive solar design are difficult to assess. Since the costs of building materials, insulation, glazing, labour, etc. are rising with inflation, it is to be expected that the capital $/GJ saved will also rise with inflation. However, as the costs of energy rise, each GJ saved will be more valuable, and payback periods should remain constant, or even shorten.

Simple payback periods for the passive solar buildings mentioned, at a 1981 energy cost of about $6.00/GJ, average about 19 years. ("Simple payback" is a crude but useful measure which assumes that capital and energy costs increase at the same rate). This is uneconomic to many investors, but is within the life span of building components. If energy costs rise faster than inflation, the "exact" payback period (accounting for differing interest rates and energy cost escalations) will be shorter than the simple payback period, making the investment more attractive; if they rise more slowly than inflation, the exact payback will be longer.

In general, energy conservation measures and solar energy systems are, like many other commodities, subject to declining marginal utility; that is, the first dollar spent is the most economic, and the last dollar spent is the least economic. If a conventional building is relatively energy inefficient, major energy savings can be achieved at a low cost. As conventional or comparison building energy conservation standards are improved, it will cost more and more to achieve significant energy savings beyond those standards.

- Conclusions

Passive solar gains occur in any building which has windows facing east, west, or south. Passive solar design is concerned with controlling and optimizing this solar gain; making use of it when needed, restricting it when not. Architectural and mechanical systems design is really a "common sense" low technology process of developing climatically responsive buildings, in which other aspects of energy conservation, particularly insulation, and air infiltration, are carefully considered.

Passive solar design need not incur major additional construction costs because it is largely a re-arrangement of conventional building components. Virtually any low rise building with windows and space heating needs is a candidate for passive solar design. The building forms des-

igned to take full advantage of passive solar gains may differ somewhat from conventional construction. They will probably be characterized by large amounts of south facing glass, predominant (although not essential) orientation along an east-west axis, and roof profiles designed to bring light into all parts of the building. Low rise buildings with low north facades generally have a minimal shadow impact, and permit buildings to be spaced closely together. Site planning will be concerned both with the three-dimensional building envelope and the relationships between buildings on the site, as well as off the site.

## 2.1 (b) Active Solar Systems

Active solar systems are adaptable to a range of building types and functions such as space heating and cooling, and the heating of fluids such as water and air. An active system comprises a set of components separate from the building components, but usually attached to them: collectors: usually roof-mounted glazed panels with internal absorptive panels to convert solar energy to thermal energy; a circulating loop which transfers thermal energy to a transport fluid (such as air, water, or anti-freeze solution) by means of a system of piping and pumps, to the point-of-use or to a heat storage reservoir; heat storage reservoir (required if the thermal energy is not to be used directly) of thermal storage materials such as rocks, water, or chemicals; and a thermostatic control system to control distribution of the heat from storage to point-of-use, by mechanical means. Depending on the system, other components (heat exchangers, expansion tanks, draining mechanisms, etc.) may also be required.

Energy flows in an active system are maintained by pumps. Failure can cause overheating in the collector, with resultant damage to it or the transport fluid. Thermal saturation of the heat storage reservoir can also damage the system unless the excess heat is discharged.

- Collectors

The design of attractive, reliable, low cost collector systems is critical to the future of active solar systems, since much of the cost of solar systems is attributable to collectors, and they are often highly visible. Since the sun only provides about 1 kW/m$^2$ of energy at its peak, solar collectors often must cover substantial areas.

The major types of solar collectors are flat-plate, concentrating, and evacuated tube.

Flat plate collectors are designed to collect as much solar energy as possible, at lowest possible cost. The temperatures required for space and water heating are moderate (not more than 93$^o$C), and can generally be attained by flat plate collectors.

The collector consists of one or more glazings which cover an absorber plate with passages, tubes, or fins for conducting a heat transfer fluid. This fluid is introduced and discharged through headers at the top and bottom of the collector. The back of the absorber plate is insulated, and the entire assenbly is mounted in a casing (Figure 13).

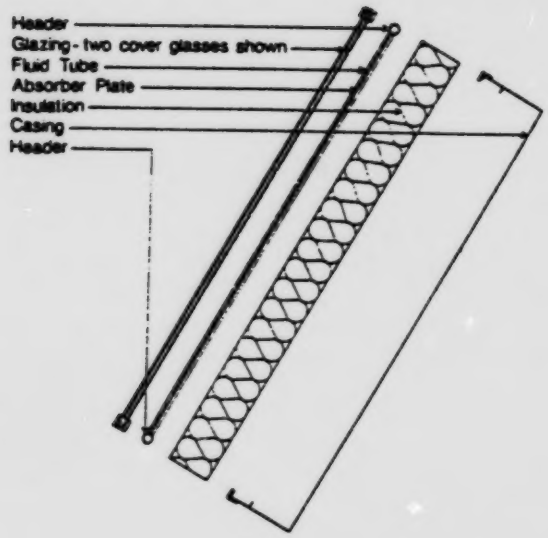



Figure 13: Exploded Cross Section through a Double-Glazed Flat Plate Collector

(Source: ASHRAE Handbook, 1978)

Heat transfer fluids can be water, anti-freeze, organic liquids, or air. Absorber plates for fluids are generally of steel, copper, or aluminum, with coatings to improve absorption; absorption plates for air flow must have a large contact area, and are made in various expanded metal meshes. These combinations of materials and manufacture have resulted in a variety of collector forms. (Figure 14 illustrates a typical air collector installation).

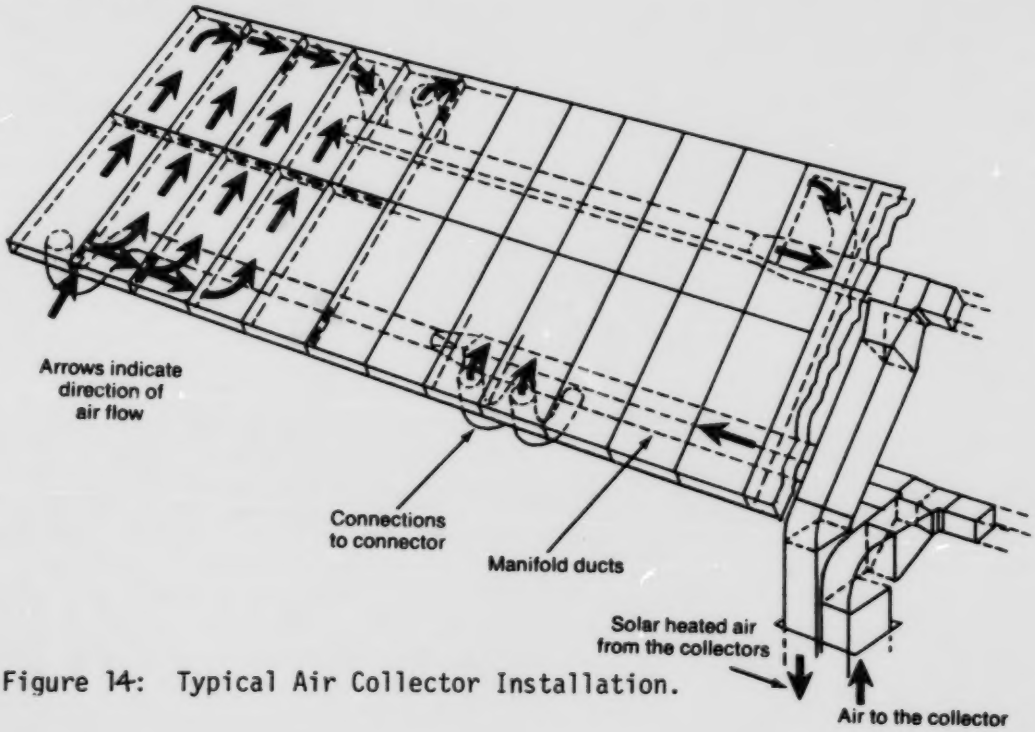

Arrows indicate direction of air flow
Connections to connector
Manifold ducts
Solar heated air from the collectors
Air to the collector

Figure 14: Typical Air Collector Installation.

Flat plate collectors are usually fixed in position at a tilt angle which maximizes the annual radiation for the desired purpose. For hot water heating, with relatively constant year-round demand, the best tilt angle is the location's latitude degrees + 15° (= 60°+ in southern Ontario). For space heating only, with higher demands in winter, the tilt angle is closer to vertical; i.e. 75 to 90°. Orientation should be due south.

As in passive solar design, the principle of an active solar glazed collector is based on the "greenhouse" effect occurring within the collector: i.e., the glazing lets short-wave visible radiation in, but does not let long-wave radiation, emitted by the absorber plate, out. The efficiency of a flat plate collector varies with the time of day (orientation towards the sun) and weather conditions (which affect heat loss from the collector). A good collector efficiency under optimal operating conditions could be as high as 70% (of incident solar energy converted to thermal energy). However, efficiencies of 30 to 40% are more probable when outdoor temperatures are low.

For certain low temperature applications (such as daytime industrial process water pre-heating, or swimming pool heating) where the solar energy is used directly, the collector may consist only of the absorber plate, without the glazed cover. Selective coatings have been developed to improve the absorptivity and decrease the emissivity of absorber plates.

Other forms of collectors have evolved from the flat plate type, in order to improve on its performance where required for certain applications. Collectors of the same aperture area cannot receive any more solar energy than a flat plate, they can only increase the temperature or intensity at which thermal energy is made available, an important characteristic in some instances.

Concentrating collectors are employed when temperatures higher than those attainable with flat plates are required, as in some industrial processes and commercial systems. (The temperatures achieved with flat plate collectors are generally adequate for most residential applications). Solar radiation is concentrated from a large receiver area onto a relatively small absorption area. Various geometric forms have been developed to achieve this concentration. (Figure 15).

Because of the apparent movement of the sun through the sky, most concentrating collectors must be able to follow this motion in order to provide a continuously high performance. This motion is referred to as tracking. For extremely high inputs of radiant energy, a multiple array of flat mirrors called heliostats can be used to direct solar radiation onto a common target; for example, a steam generator in a thermal power generating plant.

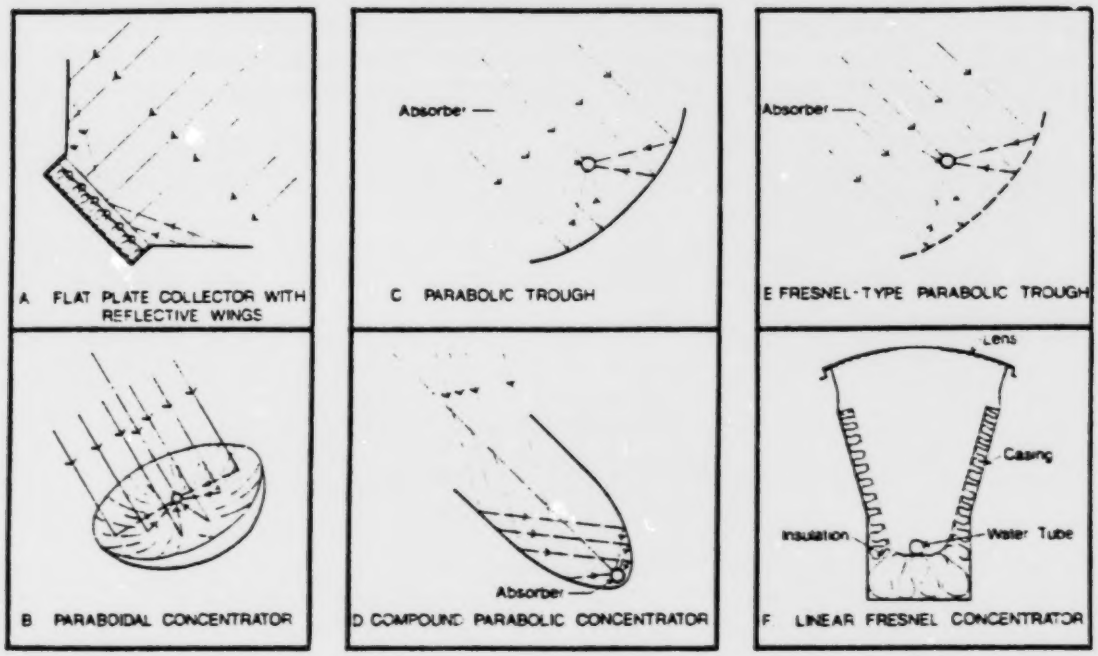



Figure 15: Types of Concentrating Collectors
(Source: ASHRAE Handbook, 1978)

Evacuated tube collectors are more expensive than flat plate collectors, but operate at slightly higher temperatures. The excellent insulation created by the vacuum preserves their operating efficiency in cold weather, and partially offsets their added costs. The tubular concept eliminates insulation in the back of the absorber plate, and can be lighter than comparable flat plate type collectors. Applications are similar to those for flat plate collectors, such as domestic hot water heating. (Figure 16).

Pond collectors are a fourth type of collector, which can be used when sufficient level ground is available near a site or application in which relatively low temperature fluids are required. Systems are most useful when combined with long term thermal storage, or when used directly for industrial processing preheating applications, since less output is provided during winter months. For conditions typical of many solar heating systems in Ontario, the energy output occurring during the coldest 6 months of the year is only 5 to 16% of the total annual output. As a result, the attractiveness of solar ponds used for space heating would be greatly increased if low cost techniques for long term thermal storage could be developed.

(Photo Courtesy Solartech Ltd.)

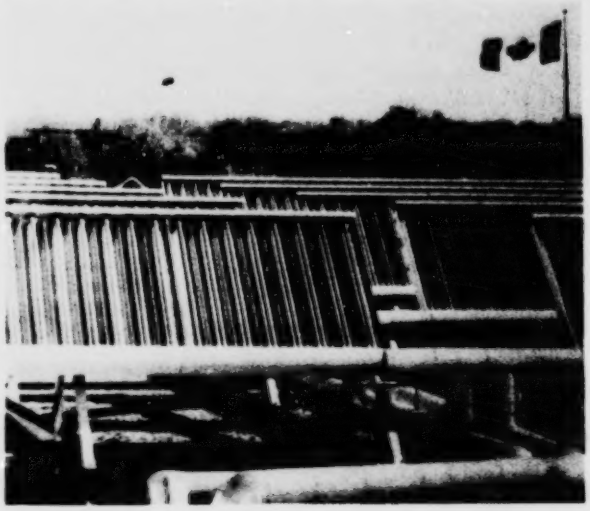


Figure 16: Evacuated Tube Collector Array

A variety of designs have been developed, based on pools or troughs of water, lined with vinyl swimming pool liners, and covered with PVC "glazing". Water is pumped slowly but continuously through the collector. (Figure 17)

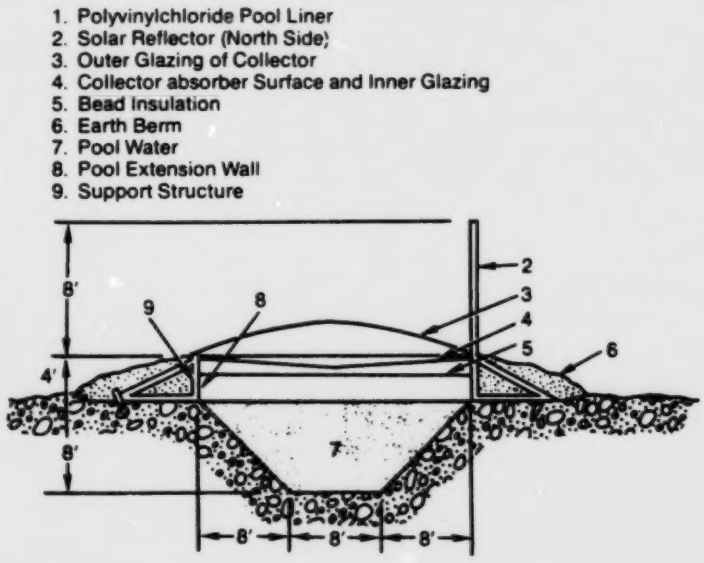



Figure 17: Typical Solar Pond Design

(Source: U.S. Office of Technology Assessment: Application of Solar Technology to Today's Energy Needs, Vol. I, 1978, p.258

Other pond collector designs are based on non-circulating stratified layers of pure water and salt solutions. Such "salt gradient" ponds are essentially a body of water 1.5 m deep which is initially filled with a strongly concentrated salt solution and then topped off with fresh water. The bottom of the pond is darkened in order to absorb the solar radiation which passes down through the water. (Figure 18).

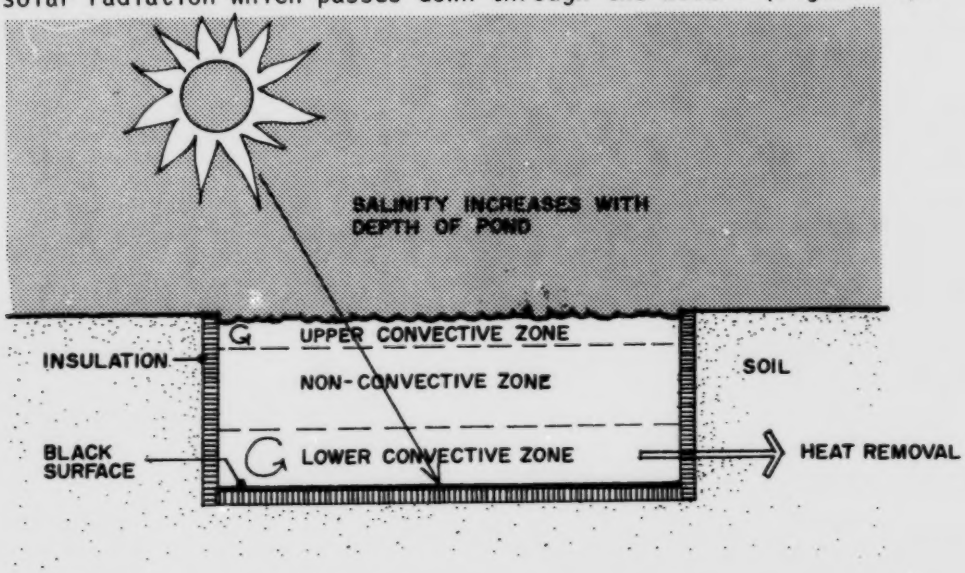



Figure 18: Salt Gradient Stabilized Solar Pond Collector

In operation, the heat from the sun warms this bottom layer and causes a narrow convective loop within it. This convection is unable to move higher in the solution since its density is still greater than the water nearer the surface. Under good conditions, where the upper level is also receiving some long wave radiation from the surrounding air, the lower salt layer can heat up to 60 to 90$^{o}$C. The ground below the pond should be well insulated to prevent heat losses during the heating season. Performance can also be enhanced with reflectors during winter months.

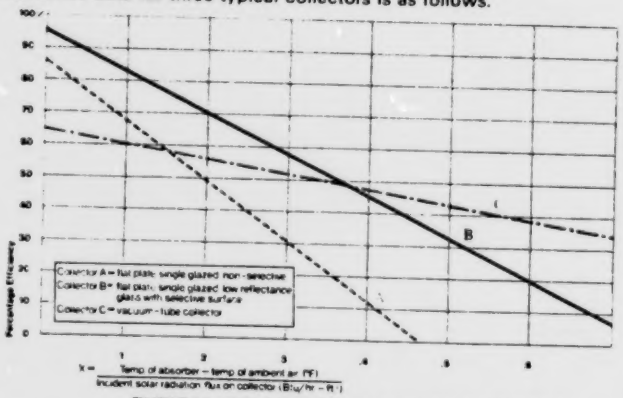
A 1500 m$^{2}$ pond has been built in Israel where it is being used as the heat source for a 6 kW electrical power generator, employing a similar technique to that of a conventional steam power plant, but using low boiling temperature freon instead of steam. Pond collectors could also be used with heat pumps for a variety of space heating applications. Heat pumps operate on the reverse of the refrigeration cycle: in the heating cycle, indoor air absorbs heat from a refrigerant, which in turn acquires its heat from an outdoor condenser which extracts it from outside air, or piping passing through a solar-heated pond.

The performance of flat plate collectors varies with outside temperature. Colder temperatures result in more heat loss by the collector, and conversion efficiency goes down. Different surfaces and assemblies also have different rates of heat absorption at different temperatures (Figure 19).

## *Performance Data*

Most manufacturers in North America have made arrangements to have their collectors tested using standard procedures developed by the United States National Bureau of Standards and the American Society of Heating, Refrigerating and Air Conditioning Engineers. This information is available to prospective purchasers of their products.

Performance data for three typical collectors is as follows.




TYPICAL COLLECTOR PERFORMANCE DATA

Collector performance data: United States National Bureau of Standards
Source: Dr. Harold A. Blum
Solar Engineering, April 1976.

To illustrate how collection efficiency can be estimated, consider the following conditions: average absorber temperature is 100°F (absorber temperature is the average of the liquid entering and leaving temperatures), air temperature is 30°F ($\triangle T$ = 70°F), incident solar radiation flux (intensity of solar radiation falling on the collectors) is 140 Btu*/hr/sq.ft. (weak sunshine). "X" then has a value of 70 divided by 140, or 0.5. Under these conditions, collector "A" would give no useful heat output, while "B" would collect about 35% of the solar radiation falling on it and transfer this as useful heat to storage.

Collector "C", which has a flat characteristic typical of an evacuated tube collector, would collect about 45% of the solar radiation falling on it.

The curves can be used as an approximation of average collection efficiency over a period of an hour without a great loss of accuracy. However, if attempts are made to use the curves with average daily radiation and temperature data, the performance prediction would be very approximate.

The performance of solar collectors over long periods is usually simulated on a computer using hourly temperature and radiation data.

**A Btu (British Thermal Unit) is the amount of heat required to change one pound of water through one degree Fahrenheit (°F).*

Figure 19

Glazed collectors are more efficient that unglazed collectors, but the latter are used primarily in direct use daytime or warm weather applications (such as outdoor swimming pool heating) where heat loss considerations may not be as critical. Evacuated tube collectors are efficient under most weather conditions because of the insulating value of the vacuum which separates the inner delivery tube from the outer absorber tube.

Snow build-up generally does not reduce collector performance if the tilt angle is sufficient to shed the snow once the collector warms up. Rain and snow can actually have a beneficial effect in washing away dust particles from the collector surface. Metal parts cool at night, and can cause condensation which may damage metal components or coatings over time.

Freezing of a transfer system fluid such as water is possible on winter nights in Ontario, therefore, anti-freeze is generally added. Other media such as air do not freeze, but are less efficient than fluids for conveying heat to storage tanks. Also, the addition of anti-freeze or other chemicals to the fluid may hasten corrosion of the piping system.

Active collectors are mounted externally on the building while the piping and storage systems are internal to the building. Therefore, the piping system must penetrate the roof structure at several points, resulting in potential places for leakage in the roof membrane. The external joints of the system are subject to high temperature stresses, with high internal fluid temperatures, and varying external air temperatures:low in winter, high in summer. This puts a great deal of expansion and contraction stress on materials, and over time, periodic inspection of the components of an active system will be necessary to ensure that joints, piping, and flashings have not failed.

- Heat Storage

There are three basic approaches to storing thermal energy:

1. Heating a liquid or solid which does not melt or otherwise change state during heating. This is called "sensible heat storage", and the amount of energy stored is proportional to the system's temperature.

2. Heating a material which melts, vapourizes, or undergoes some other change of state at a constant temperature. This is called "latent heat" storage.

3. Using heat to produce a chemical reaction which will then release this heat when the reaction is reversed. No practical systems have emerged using this approach, but research indicates that attractive technologies will soon be developed.

Sensible Heat Storage stores heat by change of temperature in a material such as water, or rocks. Heat flow is reversible, since no chemical changes are involved, and storage media such as water and rocks are universally available and cheap. Water can store 3 times as much heat as rock within a given volume, but requires containers which can resist corrosion and water pressure. Rock storage is used with air flow systems,

and is non-corrosive. Rocks also cannot freeze or boil. Either medium requires the use of bulky insulated tanks which gradually lose heat to their surroundings, and are a major component of the cost of thermal storage. A constant output temperature cannot be guaranteed with sensible heat storage.

Water containers have the added consideration of having to resist chemical corrosion from the water internally as well as from the external ground water. This is particularly important if anti-freeze is added to the water in order to prevent freeze-up in times of little or no heat gain.

Latent Heat Storage: a variety of phase change materials have been examined for use in low temperature storage systems: inorganic salt compounds, organic chemicals such as paraffin, and solutions of salts and acids. Salt mixtures have the advantage of requiring much less volume than sensible heat storage, but require complex heat exchangers and corrosion-resistant containers. Organic compounds are attractive, but some of them such as paraffin, have a relatively large volume change (10%+) when they melt, requiring a strong containment vessel.

Paraffin and related media lose heat to the ground unless their containers are insulated, but may be less corrosive than mineral salts. Like other latent heat media, paraffin has a limited storage capacity, which is available however, over a long period of time.

Latent heat storage can supply energy at a constant temperature from a single insulated container. Materials are relatively expensive, and problems may be encountered in transmitting the thermal energy in and out of storage.

Research into Chemical Storage has focused on hygroscopic minerals or salts, able to absorb water. When dried by solar energy, these materials store energy in the form of chemical potential; when moistened, they give up heat in an exothermic, or heat-releasing reaction. Such materials could store this heat potential indefinitely, in uninsulated containers, without loss to the ground, and be used again and again without deterioration. However, such chemicals are potentially corrosive to containers unless they are made of inert materials such as fiberglass. They also have a limited storage capacity.

Chemical storage media occupy much less space and weigh less than rocks or water: 8 tons of dry salt could store more than 8 000 kWh of heat. Zeolite, a widely available and cheap mineral in Canada, has been investigated as a heat storage medium. However, it does require the higher operating temperatures associated with evacuated tube or concentrating collectors, in order to disassociate the water molecules from the salt molecules. Moistened air is passed over the chemicals in order to re-

lease heat. A disadvantage of this form of storage is that the released air is hot and dry, and usually must be humidified again for use in space conditioning. The storage chemicals must be securely closed off from air movement when not in use, because they will tend to absorb any moisture from the air, thereby losing chemical potential in the process. No practical demonstration projects of this form of storage have yet been developed.

All active storage media have definite limits on their capacities to store thermal energy. If these limits are reached and the heat is not utilized, then the incoming heat from the collector system must be expelled, resulting in a straight loss of collector output and efficiency.

- Applications

Active solar systems are used for both hot water and space heating. Domestic hot water heating (DHW) is often done separately in a system by itself, but active space heating usually includes DHW heating as well, because most building applications require hot water.

Figure 20 illustrates the simplest form of active solar application, a solar water pre-heat system, for direct use in an outdoor swimming pool. Pool water is pumped through the solar collector if the collector temperature is higher than the point-of-use. This continues until the collector and point-of-use temperatures are close, when the collector is drained until required for use again.

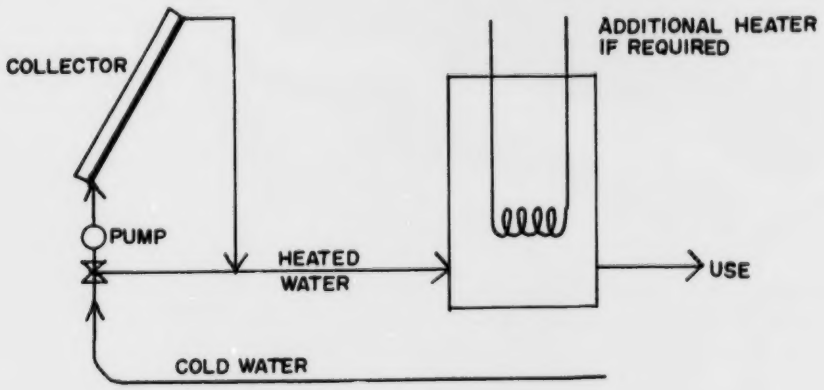



Figure 20: Solar Water Pre-Heat System

Figure 21 illustrates a typical configuration for a forced circulation domestic hot water (DHW) system. The solar collector loop is filled with water and anti-freeze, and the circulation pump transfers this fluid to the hot water heater, where the heat exchanger jacket transfers its heat to the potable water in the storage tank.

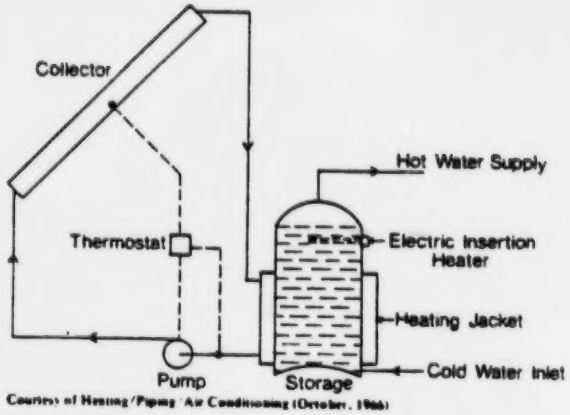



Figure 21: Typical Forced Circulation Domestic Hot Water System
(Source: ASHRAE Handbook, 1978)

Figure 22 illustrates a more complex configuration for both space and hot water heating. Both systems operate independently on separate thermostats, and "dip" into the heat potential of the storage tank, which is supplemented by auxiliary heating, if its temperature is too low for either system. The operating costs of this auxiliary heating are less than the costs of a full DHW and space heating system supplied entirely by conventional non-renewable fuels.

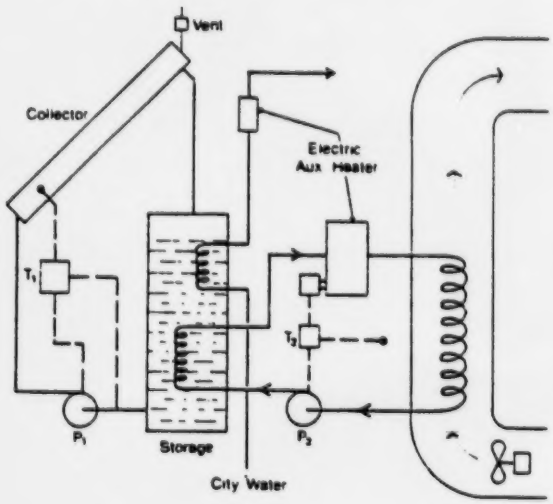



Figure 22: Solar Collection, Storage, and Distribution System for Domestic Hot Water and Space Heating
(Source: ASHRAE Handbook, 1978)

Solar energy may also be used to operate cooling equipment by using heat to energize a refrigeration cycle. Cooling systems have three basic components:

1. a unit which permits a refrigerant to expand, vapourize, and absorb heat from the room;

2. a compressor which compresses the heated vapour, increasing its temperature;

3. a condenser which rejects heat into the atmosphere, condensing the compressed vapour to a liquid.

In an absorption refrigeration cycle, a chilled liquid refrigerant (usually water) is permitted to expand and cool air. This water is then recompressed and the absorbed heat rejected into the atmosphere (right side of Figure 23). The absorption cycle accomplishes this recompression by absorbing the low pressure water vapour in a concentrated salt solution. This concentrated salt solution (usually of lithium bromide/water) is continually produced in a distilling unit (generator) driven by heat from solar or other sources.

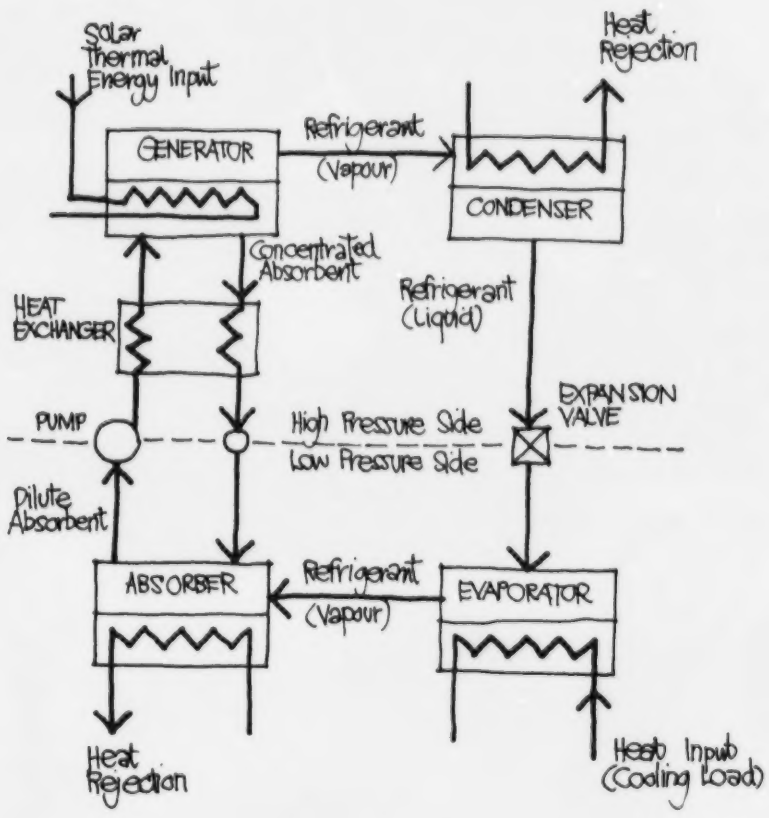



Figure 23: Basic Single Effect Absorption Refrigeration Cycle

Solar cooling systems are inherently expensive because of the large numbers of pumps, controls, and heat exchangers, and large cooling surfaces required to reject heat to the atmosphere.

• Cost-Effectiveness

Technically, active solar thermal systems can be used in 4 major types of applications:

1. water pre-heating (direct use, without storage)
2. domestic hot water (with storage)
3. space heating (with thermal storage)
4. space cooling (air conditioning).

Because active system components are separate from the building structure, their capital costs can be estimated precisely. These consist not only of solar collector panels, pumps, and piping, but also control mechanisms, structural supports, installation, and engineering design. Except for monitoring, calibration, and system maintenance, operating costs are usually very low.

The range of current (1981) capital costs for active solar systems is:

- $500+/GJ for space heating applications. Costs for space cooling applications would probably exceed these amounts.

- $200 - $400/GJ for domestic hot water systems with storage;

- $120 - $200/GJ for pool and water pre-heating applications.

Only the pool and water pre-heating active systems appear to approach the cost effectiveness ($/GJ) of passive solar systems at the present time. The high costs of active systems for space heating in particular (up to 5 times passive solar costs) have limited demonstration projects and applications in recent years.

One reason for the relative costliness of active solar systems lies in the complexity and costs of their components. Systems with thermal storage are generally at least twice as expensive as direct use (pre-heat) systems without storage. Extra costs include not only the insulated storage tanks, but also the controls, pumps, and piping to transmit energy to storage and retrieve it when needed. Additional components may also increase the operating losses of the system. Overall system costs are proportional to the number of components; therefore, even if manufacturing costs decrease, simple pre-heat systems are still likely to maintain a significant cost advantage over more complex systems.

Demand also affects the costs of active solar systems. Domestic hot water (DHW) demand is practically constant over the entire year in most applications. Therefore, solar energy absorbed by a collector can be used every day of the year. Only a small storage volume is necessary to save solar energy collected during the day for use at night or the next morning.

The consumption profile for space heating or space cooling is different - for heating, it is high for 4 months, moderate for another 4 months, and non-existent in the 4 months of summer. Solar energy absorbed by a collector can only be used during the demand months, and must be dumped at other times. A "DHW" collector therefore, delivers more usable energy over the year than a space heating collector, even if both are the same. Pre-heat systems are the most effective active solar applications because all the energy collected is used directly, with no storage losses. The cost differentials between space heating and DHW systems can only be reduced if solar energy absorbed in the summer can be stored over several months for use in the winter. In turn, this is only possible with a cheap, reliable, long term storage medium with small energy losses. No practical methods have emerged as yet.

According to Ministry of Energy projections, capital costs for active solar systems may decline by 50 to 75% over the next decade. (Figure 24) This will depend on certain factors such as improved operating efficiency of solar systems, lowered component costs through mass production, and whether energy costs rise faster than inflation.

The majority of active solar systems illustrated use roof top collector panels with the thermal storage (if provided) at or below ground level. Because collector efficiency is crucial to improving the cost-effectiveness of active solar systems, site planning and building design should ensure that collectors can be placed at optimal tilt and orientation, without blockage. Planning controls will also have to deal with the visual impact of collectors on building roof profiles. In this sense, active solar collectors are similar to projecting TV antennas or billboards, for which solutions acceptable to the community have been found in the past.

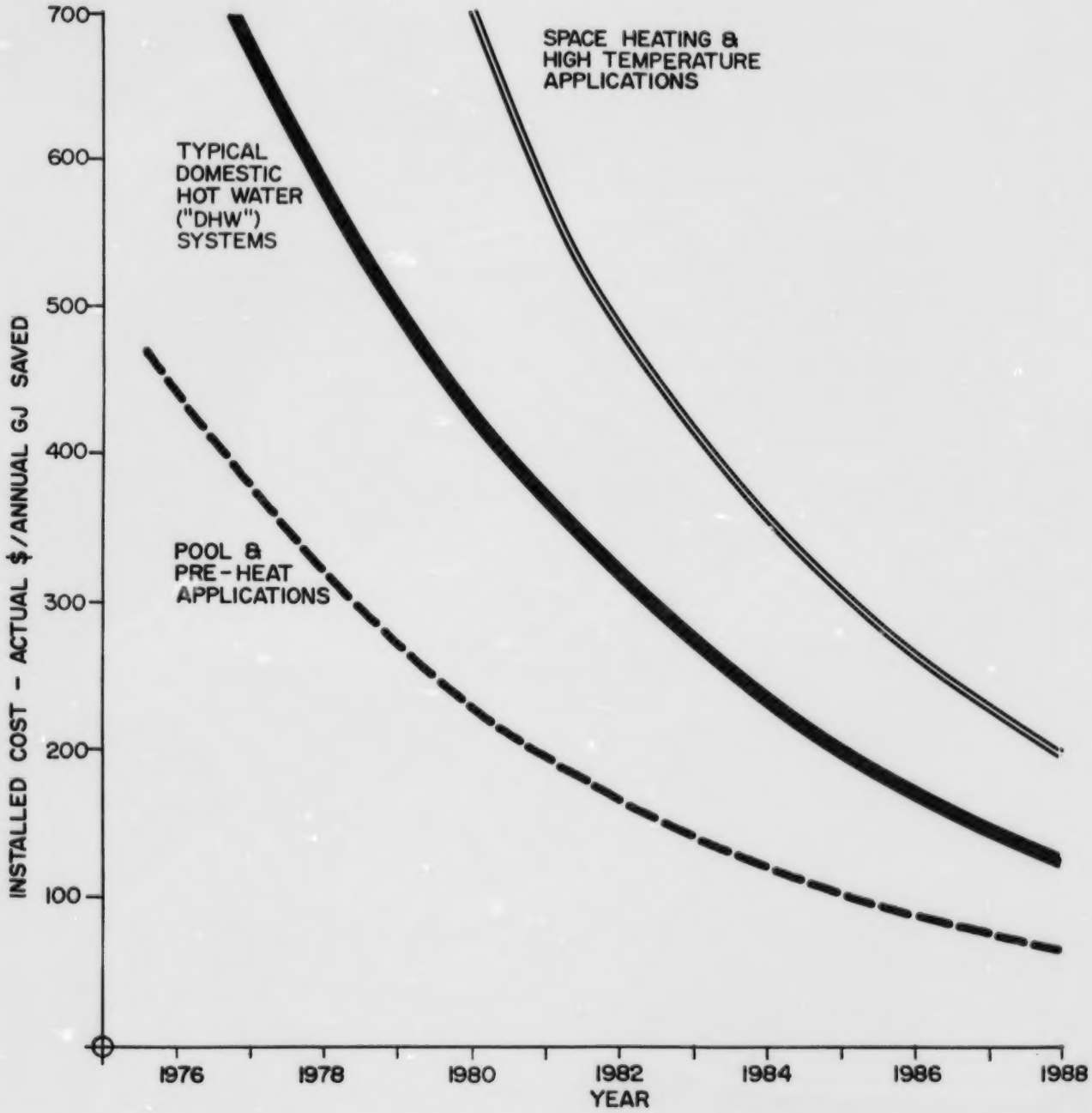


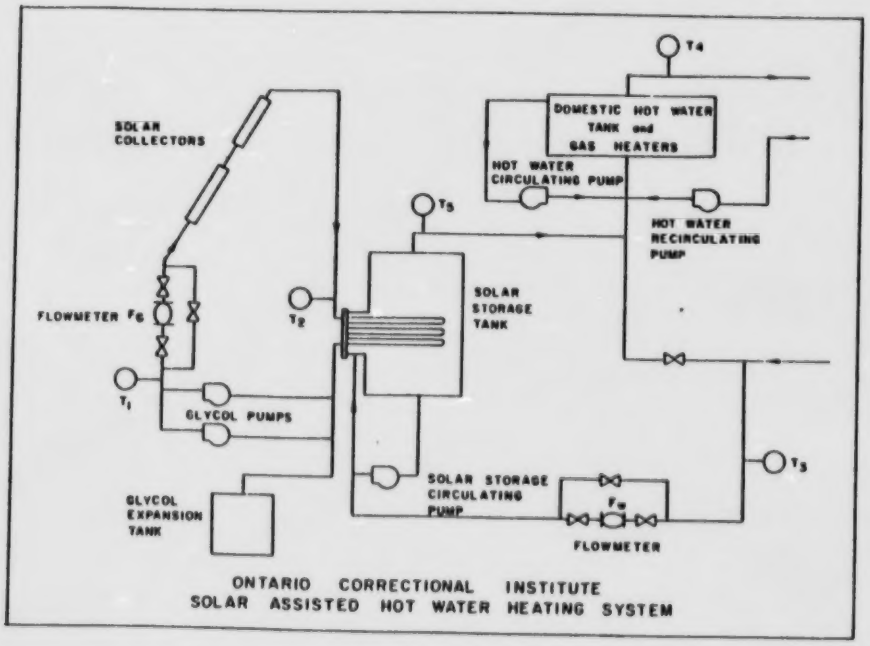

**Figure 24: COSTS OF SOLAR THERMAL SYSTEMS**
ACTUAL (TO DATE) & PROJECTED

SOURCE ONTARIO MINISTRY OF ENERGY, 1982

Case Study - Ontario Correctional Institute, Brampton

This solar retrofit project was undertaken by the Ministry of Correctional Services to reduce the costs of heating domestic hot water at the Brampton facility. The project was completed in June, 1980.

Solar Components: The solar collectors consist of 56 panels with a collector area of 95 $m^2$. The collector fluid used is a 50% propylene glycol/water solution. The heat collected through the solar panels is stored in a 7570 l tank. Two gas fired hot water heaters with a capacity of 87.9 kW each are used for auxiliary heating.




Costs: The installed cost of the complete system in 1980 was $73,000.

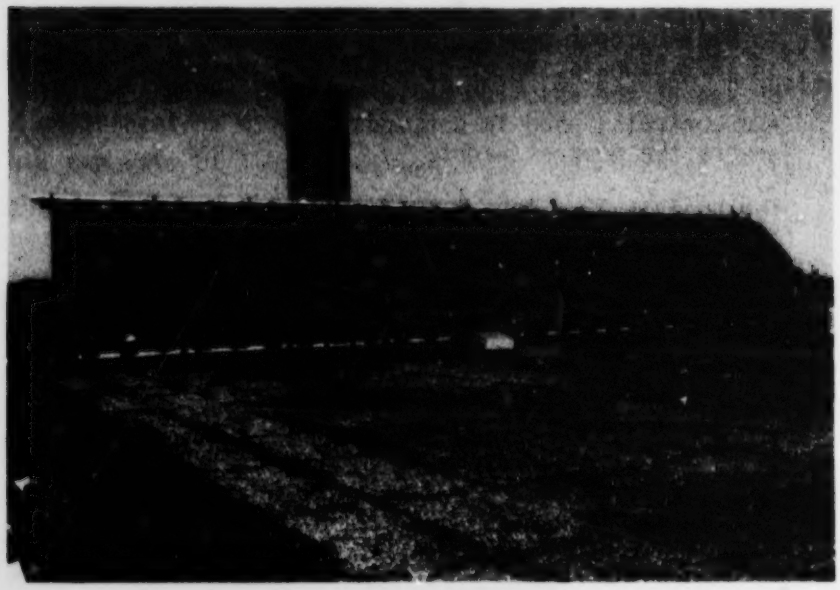
Solar energy collected = 223 GJ (1981)

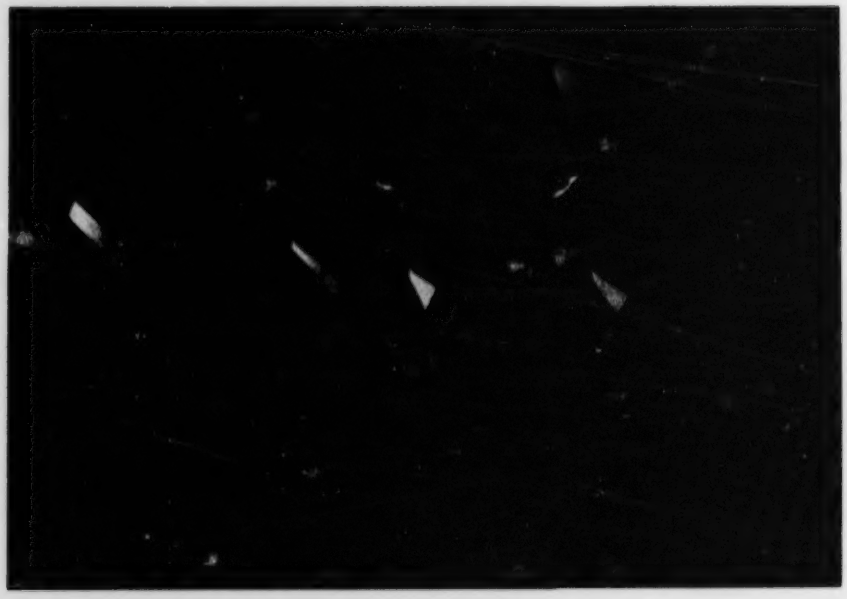
Fuel units saved (assuming 80% efficient water heater) = 268 GJ

Capital Costs: $/GJ = $272

This project was financially supported by the Ministry of Energy.

Case Study - Ontario Correctional Institute, Brampton





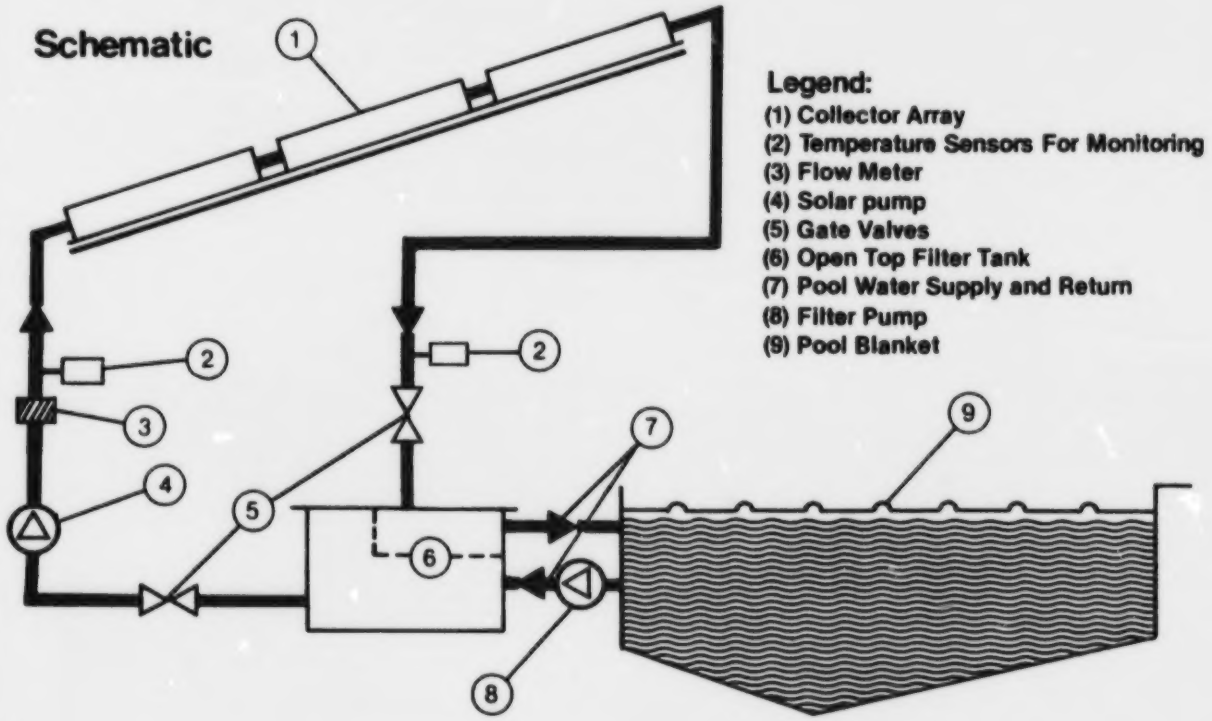
Case Study - Richvale Community Centre Swimming Pool

This project, the first municipal pool solar heating system in Ontario, is a demonstration of the feasibility of using solar energy systems to heat outdoor pools. This is a retrofit application, installed in 1979, consisting of a collector array, wood structural supports on top of the existing building roof, and accompanying pumps, piping, and controls, used in conjunction with an insulating blanket that covers the pool at night.

The pool is 25 m long x 13.7 m wide, and serves a local population of 35,000 from the Richmond Hill area, from June through September.

Solar Components: 228 single glazed, liquid flat plate collectors with an area of 160 $m^2$ are mounted on the Community Centre roof. Collectors are sloped $7^0$ and face $34^0$ east of south.

Pool water is pumped from the filter tank through the collector panels when the differential of the water temperature in the collectors is more than $4.4^0C$ higher than the pool temperature. The pump circulates pool water through the collector until the collector temperature is within $1.7^0C$ of the pool temperature. When this occurs, the pool water in the collector panels is drained back into the filter tank.




This project was financially supported by the Ministry of Energy.

Case Study - Richvale Community Centre Swimming Pool, Continued

Costs: The installed cost of the system, including collector panels, plumbing, and hardware, controls, electrical wiring, installation, and structural lumber, was $12,306 in 1979, or $13,536, adjusted to 1980.

There are two ways of looking at the costs and benefits of the system:

(1) In terms of the fuel units saved (for example, if a natural gas hot water heater had been used to heat the pool):

Energy collected = 97.1 GJ

Fuel units saved (assuming an 80% efficient water heater) = 116. 5 GJ

Capital Costs: $116.18/GJ saved (1980)

Simple Payback (@ $6.00/GJ) = 19 years

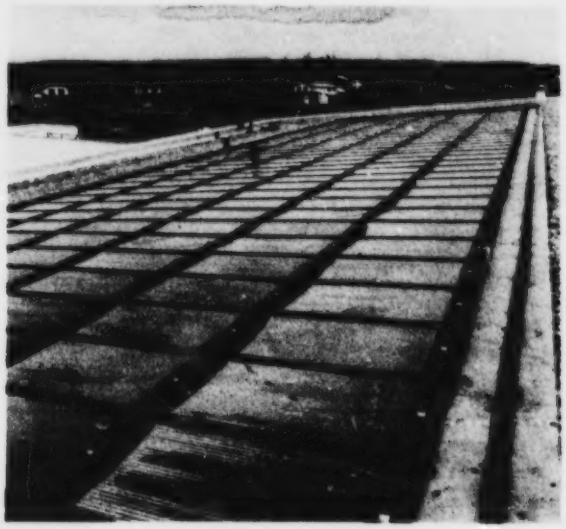
(2) In terms of increased attendance and revenues because the pool is better heated (assuming no other heating used)

Increased revenues (1980 - 1978) = $14,522 - $8,480 = $6,042.

| | |
|---|---|
| Operating costs: solar system costs ($210) + additional pool chemicals (1980 - 1978: $570) = $210 + $570 = | (780) |
| Net revenues | $5,262 |

Simple payback = 2.5 years.

On this basis the installation is very attractive.



Case Study - Talisman Resort

Talisman Resort is a year-round recreation centre in Beaver Valley, consisting of a 42 room hotel ("Alpine Lodge") with dining rooms, meeting rooms, bars, and year-round outdoor swimming pool, and a 40 unit motel ("Beaver Lodge") overlooking the ski slopes and golf course.

Solar Components: Active solar roof-mounted collectors were installed to supplement conventional systems, to supply:

- domestic hot water for Alpine Lodge (kitchen and dishwashing purposes) - 30 collector panels
- domestic hot water for Beaver Lodge (motel and laundry hot water) - 42 panels
- outdoor swimming pool - 16 panels mounted on the Alpine Lodge roof.

There are 3 basic groups of equipment for each installation:

- primary equipment to collect and store solar energy
- control system to monitor and ensure the safety of the installation
- interphasing system to allow the existing facilities to be operated with the new solar heating installation.

Costs: The installed costs of all 3 systems, including design engineering, building modifications, solar collector panels and structural support, solar system equipment (storage tanks, heat exchangers, pumps, piping, fixtures, insulation), control equipment, and installation, was $132,400 in 1981.

Energy collected = 368 GJ

Fuel units saved (assuming 80% efficient water heater) = 441.6 GJ

Capital Costs: $/GJ = $299.82

This project was financially supported by the Ministry of Energy.

Case Study - Christie, Brown & Company

Christie, Brown & Company is a manufacturer of food products in Toronto. Being the largest manufacturer of biscuits and crackers in Canada, it makes use of 400,000 $ft^2$ of office and manufacturing space, and employs over 1,000 people.

The roof of the facility is composed of precast concrete slabs supported by structural steel beams. A portion of the roof is designed with useful skylight dormers, sloped southward at an angle of $25^{o}$.

Solar Components: The solar water pre-heating system which has been installed is an "open loop, drain back" type, meaning that the collector panels and piping can be drained free of transfer fluid while the system is shut down. The support racking and accompanying 160 collector panels are located on two of the most northerly skylight dormers of the existing building.

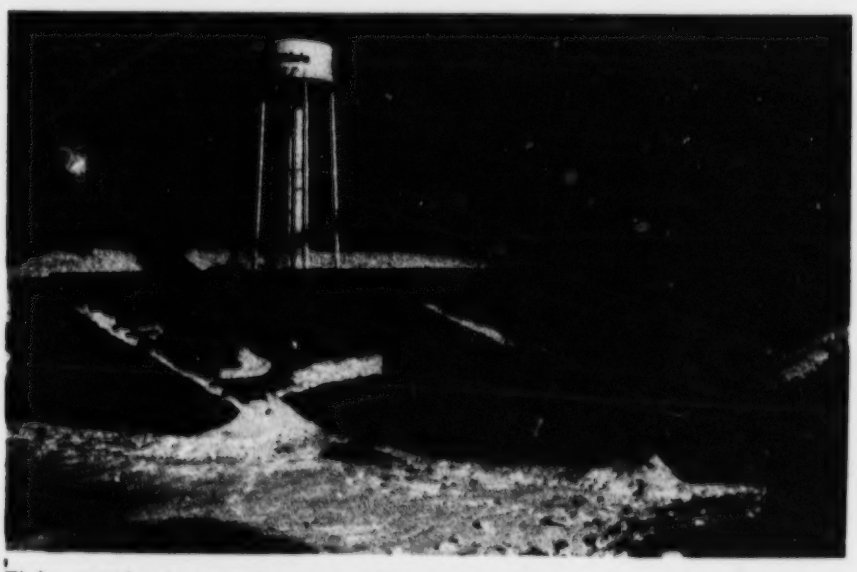
The overall solar heating system is made up of two distinct energy systems: a primary system collecting and controlling water heating by solar energy, and a secondary system absorbing heat energy from the system, eventually to become part of the domestic hot water system.

Costs: The installed costs of the system, including design, building modifications, collector panels, equipment, controls, and installation, were $222,600 in 1981.

Energy collected = 709 GJ

Fuel Units Saved (assuming an 80% efficient water heater) = 850.8 GJ

Capital Costs: $/GJ = $261.64



This project was financially supported by the Ministry of Energy.

Case Study - Inglis Carpet Cleaners Ltd.

Inglis Carpet Cleaners is located in a 1 storey industrial building in suburban Ottawa.

Solar System Components: The solar collector system comprises 68 (220 $m^2$) Amhert 200 air collector panels. Included in the system is a heat exchanger on the collector inlet duct which is used to partially pre-heat the service hot water and to partially de-humidify the building air.

Since the carpet cleaning operation is only carried on during the day, no thermal storage was included in the solar system. It is therefore a highly reactive system, in the sense that its actual usefulness to the end-users will depend very much on the manner in which they adapt to it. In other words, if the end-user merely treats it as a conventional heating device and does not adapt his operation to the availability of solar energy, the system can be expected to save about 1/3 of his conventional heating costs. On the other hand, if he takes steps to maximize its benefits, this contribution could be as high as 2/3.

Costs: The installed cost of the system in 1981, including design costs, solar collectors, mounting racks, electrical, mechanical equipment, and installation labour, was $86,500.

Energy collected = 500 GJ

Fuel units saved (assuming an 80% efficient water heater) = 600 GJ

Capital Costs: $/GJ = $144.17

This project was financially supported by the Ministry of Energy.

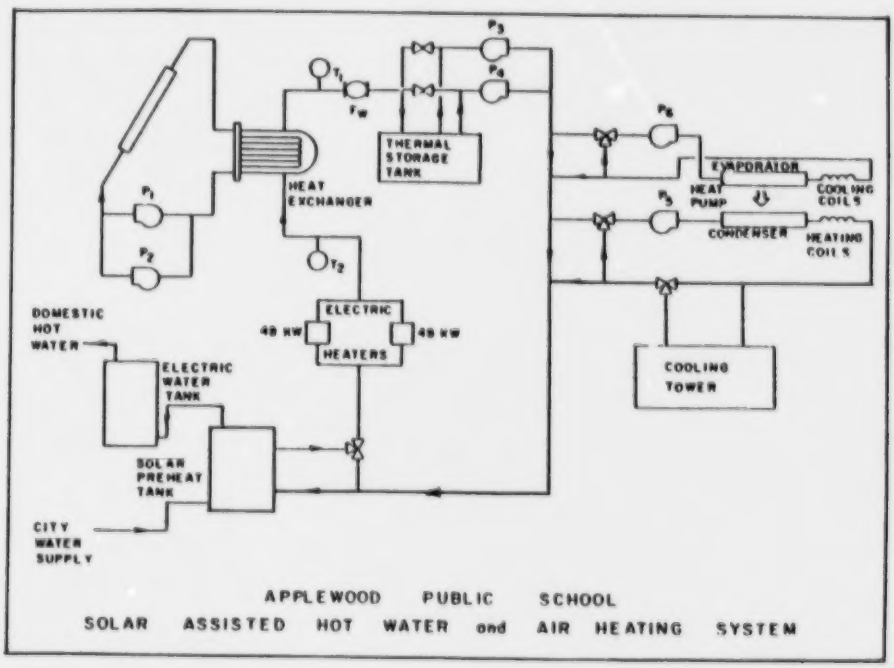
Case Study - Applewood Public School, St. Catharines

The school is a 1978 demonstration project designed to be energy-conserving, and to employ solar energy to supplement the building's space and domestic hot water heating needs.

The school has a gross floor area of 1,918 $m^2$ and is well insulated. The academic section of the building is a two storey structure, and corridor spaces are located adjacent to exterior walls to provide a thermal buffer between the exterior and occupied spaces. Window areas were kept to a minimum and are double glazed.

Solar Components: 230 $m^2$ of single glazed, flat plate liquid collector panels are employed in the building. The liquid used in the collector is a 50/50 glycol/water mixture. Surplus energy is stored in a 45,400 l insulated water tank adjacent to the building. The collected heat energy is distributed through the building via a forced air system.

The solar heating system is assisted by a heat pump which provides for partial solar heating and air conditioning. The back-up system uses 2 two-stage 48 kW electric off-peak hot water circulation heaters, to maintain a minimum thermal storage temperature.




APPLEWOOD PUBLIC SCHOOL
SOLAR ASSISTED HOT WATER and AIR HEATING SYSTEM

This project was financially supported by the Ministry of Energy.

Case Study - Applewood Public School, Continued

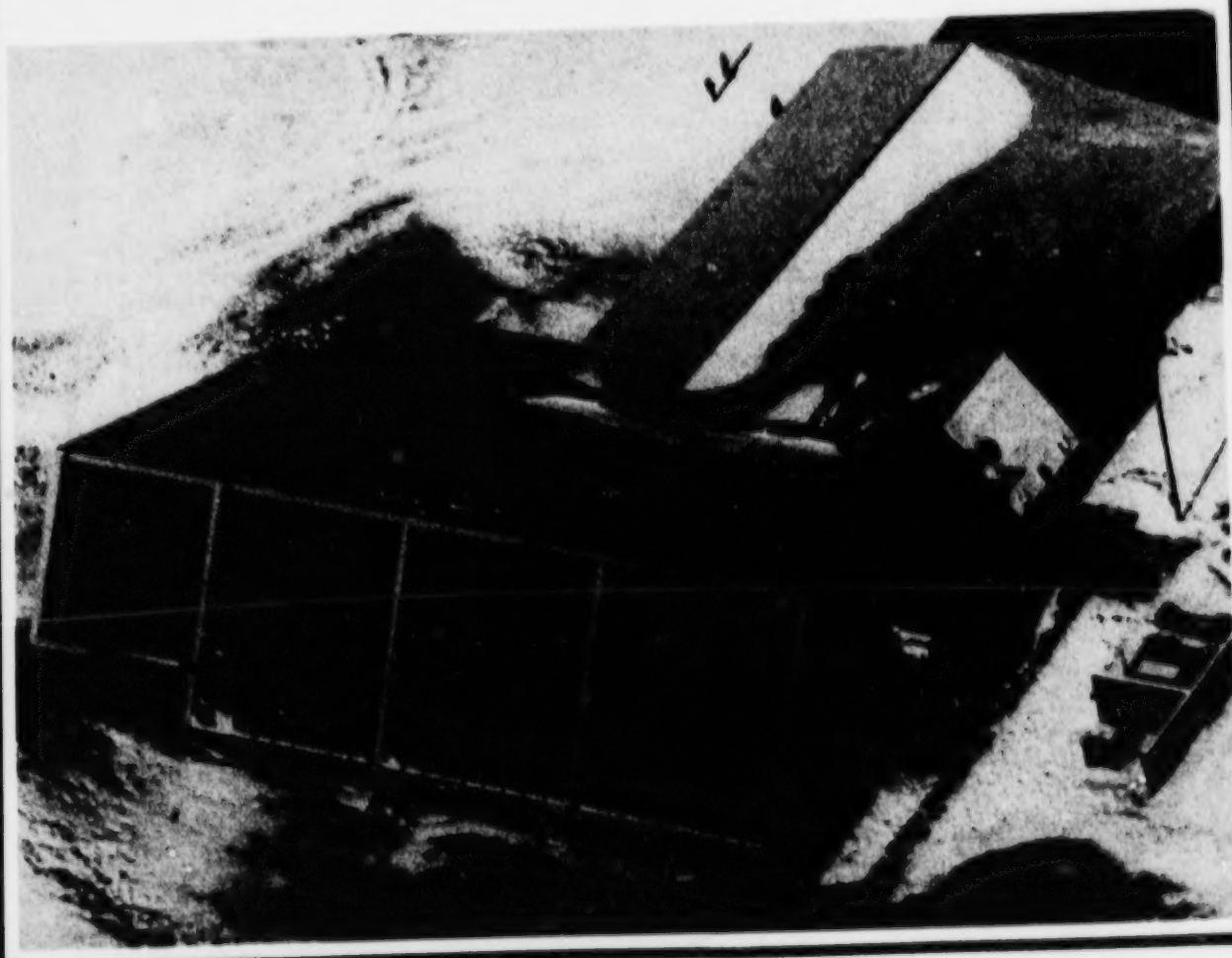
Costs: The initial cost of the solar system, including design fees, was $227,800 in 1978. Escalated ot 1980 figures, the cost was $275,600.

Due to monitoring equipment failures, no actual performance figures are available for this project. The design solar energy contribution for both space heating and water heating was estimated to be 362 GJ.

Fuel units saved (assuming a 95% efficient hot water heater and furnace ) = 381 GJ

Capital Costs: $723.65/GJ saved.

The high capital cost investment for active solar space heating is amply demonstrated in this project. Confining the solar system to domestic hot water heating only would have been more cost-effective.



Case Study - Medallion Film Laboratory

Medallion Film Laboratory is located in downtown Toronto, in a single building with two distinct areas. The lower portion of the building consists of a two storey wood frame structure. The higher portion of the building consists of a four storey concrete structure.

The hot water heating system consists of several gas fired heaters located on the first floor and basement of the laboratory. The major consumer of water within the laboratory is the film processing machinery located on the first floor, consuming 95,000 l of hot water per day, with an annual energy consumption of 789 GJ.

Solar Components: A solar hot water heating system has been installed to supplement existing domestic hot water heating. Because the collector panels are located on two separate roof levels, the overall system combines two separate pumping loops and one central storage and control system. The lower roof level supports 69 collector panels, while the upper roof supports the remaining 72.

Costs: The installed cost of the system including design, building modifications, collector panels, structural support, controls and installation labour, was $187,380 in 1981.

Energy collected = 798 GJ

Fuel units saved (assuming an 80% efficient water heater) = 957.6 GJ

Capital Costs: $/GJ = $195.68

This project was financially supported by the Ministry of Energy.

## 2.2 Electrical Processes

Electricity can be generated from sunlight in two ways: by using photovoltaic cells (solid state devices) which produce electricity directly, without moving parts; and by heating fluids to operate heat engines (such as steam turbines) which turn electrical generators.

### 2.2(a) Photovoltaic Systems

Photovoltaic cells are semi-conductor devices which produce electricity when exposed to sunlight. They have several advantages:

- no moving parts
- no high temperature or high pressure fluids
- reliability, safety, and ease of operation
- cells can be produced with silicon, one of the earth's most abundant elements.

A typical photovoltaic installation consists of an array or cluster of small individual generating units or cells (Figure 25). Many types of cells and materials are currently available, having evolved from the simple solar power cells used to power space satellites more than a decade ago.

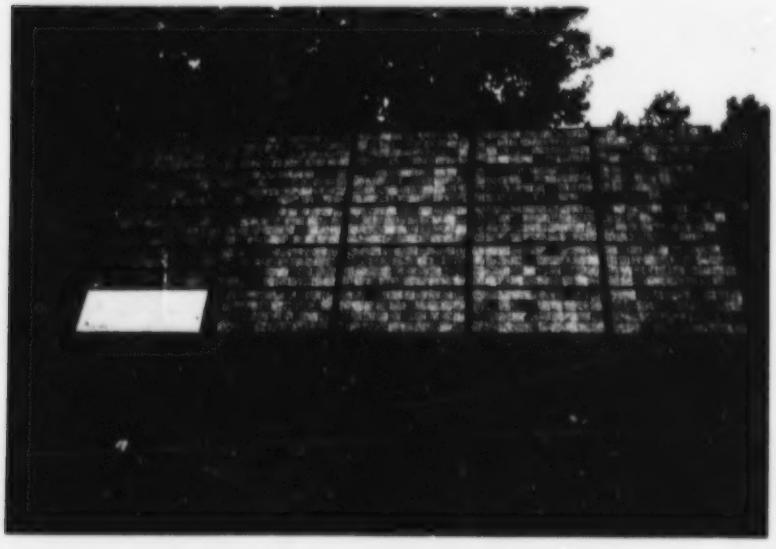
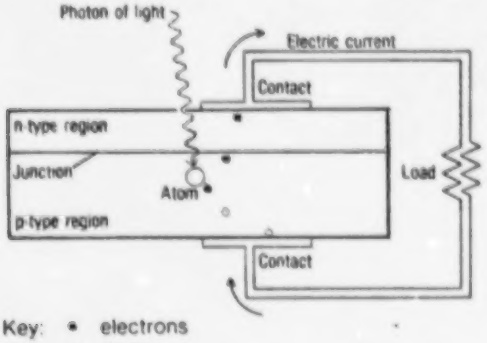


Figure 25: Photovoltaic Cell Array

In an individual solar cell, the energy in sunlight is transferred to electrons in a semi-conductor material, when a light photon collides with an atom in the material with enough energy to dislodge an electron from a fixed position, enabling it to move freely in the material. A vacant electron position or "hole" is left behind at the site of this collision; such holes can move if a nearby electron leaves its site to fill

the hole. A current is created if these pairs of electrons and holes (which act as positive charges) are separated by an intrinsic voltage in the cell material.

The creation and control of this intrinsic voltage is the basis of semiconductor technology. The most common technique to create a voltage is to put discontinuities in the cell by adding small impurities such as phosphorus and boron to the pure material, which is typically silicon. This is called a "homojunction" cell (Figure 26). In the diagram, the "n-type" semiconductor region has phosphorus added to the silicon; and the lower "p-type" region has boron added to the silicon.




Key: • electrons
o holes

Source: After "The Sun on a Semiconductor", 1978, p. 23

Figure 26: Schematic Drawing of a Photovoltaic "Homojunction" Cell

Manufacturing processes to produce very pure silicon cell material are energy-intensive and expensive, approaching costs of $10,000 per peak kW of output (1980 U.S. dollars). These high costs are significant barriers to more extensive photovoltaic applications at the present time. Current research is directed towards reducing the costs of solar cells in several ways:

- reducing the costs of manufacturing single crystal silicon cells now on the market through technological improvements, and the use of cheaper forms of amorphous silicon;

- techniques for mass production, and increased performance from cells made from ribbons and thin films;

- developing high-efficiency cells, made of materials such as gallium arsenide, and configurations such as multi-junction (stacked) cells, able to operate at high temperatures at the foci of concentrating collectors. Current lab tests indicate that conversion efficiencies (of solar energy to electrical energy) of 25 to 50% should be possible, compared with present efficiencies of 10% or less.

It should be possible to reduce the costs of solar cell production by an order of magnitude (i.e. from $10,000 to $1,000 - $2,000 per peak kW) within several years. This would approach the capital costs of energy from new coal-fired or nuclear generating plants.

- Photovoltaic Applications

A simple photovoltaic installation can consist of an array of cells connected with an inverter, to convert the direct current produced by the cells into 60 cycle alternating current, required in most applications.

Solar cells are finding application in remote areas for installations with low power requirements, such as stand-alone marine or air navigation devices, communications, and outdoor lighting. Other potential applications include large alternating current power distribution systems for remote small villages, logging and mining camps; agricultural equipment and irrigation pumping systems; and sales of electrical power from individual installations to electrical utilities.

Small scale installations are currently feasible in Ontario in remote locations which are not connected to the southern Ontario power grid. More extensive applications in southern Ontario will arise as the costs of photovoltaic power approach an operating cost of 5 to 10¢/kWh, which is currently reached by new large generating plants.

The generation of solar electrical power at a number of dispersed on-site facilities, and its sale to local or provincial Hydro utilities, is a prospect which may have to be considered by local planning authorities over the next decade. If energy can be produced from on-site solar energy systems at competitive prices, the increasing centralization which has characterized energy industries in the post-war era could be changed dramatically; basic patterns of energy consumption and production could be changed; and energy-producing equipment could be owned by many types of groups, organizations, and individuals.

In turn, this raises the prospect of virtually any flat or sloping roof or site with the appropriate orientation becoming a candidate for photovoltaic collector panels. The need for legislation or controls to protect solar access rights in existing and new development areas would also intensify.

## 2.2 (b) Heat Engines

Heat engines operate by taking a high temperature fluid (which may be steam or a heated gas) and converting some of the fluid's energy into mechanical power or electricity, cooling the fluid in the process. The fluid which emerges from engines can be quite hot, and can still be used for space heating and other applications. While solar energy can provide high temperatures, fluids at such temperatures are expensive to collect, transport, and store, a factor which has tended to limit research and development of this technology.

A number of heat engine designs may be used in solar installations, but the small engines now on the market, which are compatible with solar energy applications, are also quite expensive. Small gas and diesel engines cannot be used easily in solar systems since they require heat applied inside a cylinder; most engines designed for solar applications must be able to operate from heat applied to some external surface, such as the boiler of a steam turbine.

The simplest approach is to use a solar collector to produce steam (at a temperature of 200 to 500°C) and use this steam in standard steam piston or turbine engines. Large steam turbines are quite economical, with efficiencies approaching 40%. Use of steam means that a high performance tracking collector system must be used, together with high temperature thermal storage. Both are expensive, and point to large scale installations to make effective use of the solar energy collected.

It is also possible to use much simpler solar collectors and storage, with engines designed to work at lower temperatures (60 to 90°C), using organic fluids like freon. Low temperature systems are reliable (essentially operating as refrigerators working "backwards"), but their efficiency is low (10% or less) and the engines are bulky and expensive.

Less work has been done on heat engine designs operating at high temperatures. These would be dependent on collector systems such as concentrating heliostat fields (mentioned above) to produce temperatures of 750°C or more, being available at a reasonable cost. There is a clear economy of scale with gas turbine technology (i.e. larger engines produce cheaper power), and these larger engines in turn require large scale collector installations. Both of these developments: sophisticated, efficient, modest cost engine designs, able to be mass produced and requiring little maintenance; and high temperature solar collector systems available at moderate cost; are still some years away.

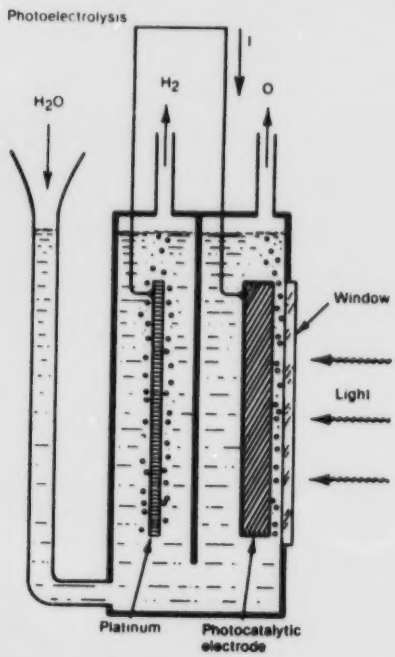
A number of demonstration projects using heat engines have been done in the U.S.A., but no practical or economical installations for electrical power generation have been developed as yet. The applications which show the most promise use co-generation, i.e. the ability to make use of both electrical power and the waste heat generated by the engine (for a purpose such as space heating). This may include many industrial processes (particularly in remote locations) and small settlements such as construction, mining, and logging camps. However, some of these applications may still depend on simplifications of engine and collector technology to the point of being rugged, light weight, virtually maintenance free, and easily repaired. As with many hot water heating applications, the value of solar energy in these instances may lie in pre-heating water or other fluids, which then must be brought up to working temperatures by other means is order for the heat engines to operate efficiently.

## 2.3 Chemical Processes

The use of solar energy to create chemicals is a technology only now being explored. Such processes would have the advantage that the chemicals produced could be easily stored or burned, much like natural gas.

### 2.3 (a) Hydrogen

About 10 years ago, Japanese scientists discovered processes by which sunlight falling on an electrode suspended in water would convert it directly into its component hydrogen and oxygen. (Figure 27)




SOURCE
Goodenough, J. B. (Professor, Oxford University, England) "The Options for Using the Sun," Technology Review (M.I.T.) 78(1), October/November 1975, pp.62-71.

Figure 27: Photochemical Energy Conversion

Photochemical technology is not as well developed as photovoltaics, and current research is confined to a few Japanese and American universities, concentrating on the direct production of hydrogen. Most of the processes under investigation still operate at low efficiencies, and their long-term stability has not been demonstrated. Almost no work has been done to determine the potential costs of such systems. Extensive applications or even demonstration projects are some time away.

## 2.3 (b) Photosynthesis

Photosynthesis is one of the most important processes in nature, by which plants convert sunlight and carbon dioxide into storable fuel sources. There is some ongoing research in the U.S.A. into the basic chemistry of this process, and there is great interest in long term applications such as the use of plant materials as fuel sources. Of course, many of our present important fuel sources such as wood and coal, are a direct result of this process.

## 2.3 (c) Conclusions

At the present time, it is difficult to speculate about what role photochemical processes could have in increasing energy supplies. This role will depend on a number of factors such as production and storage costs, and the technologies of production and applications.

For many applications, hydrogen is an ideal fuel, and could be used to power motor vehicle engines, or burned for space heating or electrical power generation. Given its high adaptability as a fuel, it is likely that production and storage of hydrogen (whether by solar or other means) would be separate from the point of use (such as a car or a house), and will probably be concentrated in large efficient central facilities, similar to power generating stations.

Stoves and furnaces able to burn some kinds of "biomass" (plant materials) such as wood, have existed for some time, and are constantly being improved. It is unclear whether photosynthesis research will lead simply to improved productivity from natural sources, or rather to new artificial processes, resulting in new products and fuels, and the corresponding need for new technologies to utilize them.

# 3. SOLAR SYSTEM APPLICATIONS

Solar energy is a distributed energy resource, as distinct from one concentrated at a small number of unique locations (such as hydro electric generating stations). Facilities to utilize solar energy must be similarly distributed, and are usually closely related to the buildings or activities served. The land use implications of more centralized collector or storage systems are discussed in Chapter 4.

Of the three types of solar conversion processes; thermal, electrical, and chemical, thermal processes have had by far the greatest number of applications. Solar thermal systems for space heating and the heating of hot water, fluids, or air, must be closely integrated with the mechanical systems of a building or industrial process, since the capital costs of pumps and piping systems, and operating transmission losses, usually mitigate against locating solar collectors too far from the point of ultimate use.

Solar electrical systems, particularly photovoltaics, may become cost-effective in individual installations by the end of this decade, resulting in virtually any roof or site with the correct orientation being a candidate for on-site energy systems. However, the connection between solar electrical power and the point of use need not be so direct, except in low power, remote, or autonomous installations. It is probably most reasonable to sell one kind of solar-generated power to an electrical utility, even if generated on the roof of a building which requires electrical energy, and purchase back from the same utility, the kinds and amounts of power required for the functioning of the building. This results because individual power requirements may differ substantially from what can be generated, converted, and stored at a reasonable cost, on site. Also, electrical power is easily transmitted between any two points with minimal losses, and at moderate cost.

Solar chemical systems have not progressed to the point where the numbers and types of potential applications can be predicted with accuracy.

Solar thermal applications then, are the most likely to be of immediate concern to municipal planners. Since solar systems must be closely linked to building heat requirements and systems, they will have a direct effect on building configuration and site layout. However, different building types vary in their suitability for solar systems for space heating or for the heating of hot water. Some buildings, because of their high internal heat gains (from people, lights, equipment, etc.) may have little requirement for additional heat; in fact, cooling may be the major space conditioning need. Other activities require relatively little domestic hot water. Still other buildings have both heat-producing and heat-requiring areas, and it may be more feasible and economical to supply one area with the excess energy from another, rather than supply it from an external source such as solar collectors.

Those remaining classes of buildings whose heating requirements are suitable for solar thermal systems are still significant, and include housing, industrial, commercial and public buildings, accounting for much of the annual dollar volume of construction in Ontario. The following discussion describes standard construction and heating/cooling requirements for a range of building types, followed by an analysis of solar potential for space heating and hot water heating, in each case. The discussion is summarized in Table 1.

## 3.1 Residential

### 3.1 (a) Single Family Detached Housing

The typical single family house is 130 to 200 $m^2$ in floor area, one to two storeys high, and is built in wood frame construction. Energy requirements are approximately 50 to 70 kWh/$m^2$/year for auxiliary uses such as lights, cooking, electricity, etc., and 100 to 150 kWh/$m^2$/year for space heating (depending on floor area, volume, and insulation levels). Under Ontario's moderate climatic conditions, summer space cooling is generally achieved by natural ventilation rather than by air conditioning.

- Space Heating (Active or Passive Systems)

In Ontario, utilizable passive solar potential can approach 30 to 40% of the space heating load (i.e. 30 to 50 kWh/$m^2$/year). When combined with conservation measures in energy-efficient homes, passive solar systems can reduce the amount of heating energy to be purchased to as little as 50 kWh/$m^2$/year. For the effective use of solar energy, short term thermal storage is required for active or passive solar systems, since the greatest part of the heating load occurs in the evening, while the greatest supply of solar energy is, of course, in the day.

Active solar systems for space heating are physically feasible if roof collector area and basement storage areas are available. The costs of active system components are generally higher than passive solar components, which can be integrated into standard construction. Conventional heating systems are still necessary in active or passive solar construction, because of the variability of incoming solar radiation, particularly in the winter.

- Hot Water Heating

There is a year round demand for domestic hot water (DHW), although peak daily demands occur in the morning, when solar energy is limited. Although auxiliary domestic hot water heating systems are still required for variations in weather conditions, active solar systems may supply a major percentage of domestic hot water energy needs on a basis competitive with other fuels, particularly if the water is used directly. Active solar systems for swimming pool heating are also economical, and are becoming more common.

### 3.1 (b) Attached Multiple Housing

Attached housing (duplexes, semi-detached, townhouses, etc.) units range from 100 to 200 $m^2$ in floor area, generally in wood frame construction, 2 to 3 storeys in height. Energy requirements are 50 to 70 $kWh/m^2$/year for auxiliary uses (lights, cooking, electricity, etc.) and 60 to 100 $kWh/m^2$/year for space heating. This is less than required for detached housing, due to generally smaller floor areas and fewer exposed walls. Summer space cooling is generally achieved by natural ventilation.

- Space Heating

In well-insulated, energy-efficient designs, up to 30 to 40% of space heating needs can be supplied by passive solar means. Although this fraction could be even greater (i.e. a solar fraction of 40% or higher), overheating problems may arise in the intermediate seasons, spring and fall.

Active solar systems for space heating are more costly than passive, and also depend on sufficient roof collector area and thermal storage volume being availabie (which is not always possible in more compact housing forms).

Back-up conventional heating systems are necessary whether passive or active solar systems are installed.

- Hot Water Heating

Depending on roof collector area being available, active solar systems for hot water heating may be feasible and economical for individual units, with auxiliary conventional heating for peak loads and poor weather conditions. Active solar systems for swimmimg pool water heating and recreation complex heating may also be considered on a project basis.

### 3.1 (c) Walk-Up and Low-Rise Apartments

Low rise apartment buildings are generally 2 to 3 storeys in height, with wood frame construction, masonry party walls, and no elevators. Unit floor areas range from 60 to 120 $m^2$, although in luxury buildings, these may approach 150 to 200 $m^2$.

Energy requirements are 50 to 70 $kWh/m^2$/year for auxiliary loads, with 40 to 100 $kWh/m^2$/year required for space heating purposes, depending on construction and insulation. Although apartment units should be inherently energy-efficient because of their limited external wall areas, these favourable characteristics are often offset by poor construction and insulation levels, particularly in older buildings.

• Space Heating

Passive solar systems are possible for individual units with favourable orientations. However, conventional heating will still be the primary means for units with less favourable orientations. Heat cannot be transferred between units by natural or forced convection warm air systems because of fire regulations.

Heating systems which act like passive solar systems are possible: excess heat is picked up from south side units, and distributed to other units requiring heat, through a fluid piping system, and individual heat exchangers in each unit. However, they are likely to be expensive for the amount of heat generated.

Active (centralized) solar systems are possible in buildings which have large roof areas for collectors in relation to the number of units, and can make provision for central thermal storage. Thermal storage (if required) can usually be provided in common basement areas.

• Hot Water Heating

Active solar systems for domestic hot water are increasingly economical (on a direct use basis) in conjunction with conventional systems (for peak loads and poor weather conditions).

3.1 (d) High Rise Apartments

High rise construction (above walk-up heights of 3 storeys +) is generally reinforced concrete, with elevators. Unit areas range from 40 to 100 $m^2$, with larger units in luxury and condominium buildings.

Energy requirements for auxiliary uses and space heating are similar to those for low rise apartments. Summer cooling is also required in some buildings, particularly if units face west.

• Space Heating

Space heating in apartments is generally by forced water circulation, therefore, passive (air) systems will not be feasible. Individual units with favourable orientations will receive some passive solar gain, which, in turn, will reduce the energy to be purchased for space heating.

The small roof areas of high rise buildings relative to the number of units probably makes the physical feasibility of active solar collectors doubtful, unless the site has sufficient area for remote solar collectors. This is probably not the case in many urban areas.

• Hot Water Heating

Apartment buildings have substantial year-round hot water heating demands, for which active solar pre-heat systems are economically feasible. Restricted roof areas in high rise buildings or limited site area (for the placement of collectors) may be a constraint. Unshaded vertical wall areas may also be used for collectors, although at a lower efficiency (50 to 75%) than correctly oriented roof collectors.

## 3.2 Industrial

### 3.2 (a) Low Rise Industrial

Conventional modern industrial buildings are generally 1 storey in height, in steel frame and joist construction, and 2 000 $m^2$ or more in floor area. Large flat roof areas are usually available.

Energy demands are usually related to the nature of the industrial processes themselves (many of which are heat-producing, and therefore, require venting, and/or cooling). For processes which do not generate much heat, and warehouses, some space heating may be required. Ordinarily, this is supplied from space heaters distributed throughout the building.

Domestic hot water loads are directly related to the needs of particular industrial processes.

- Space Heating

With large floor areas, there may be a potential for passive solar heating and daylighting supplied through roof monitors. Substantial thermal mass is often available in floors and storage materials. Active systems for space heating are also physically possible on large roof areas, but may not be necessary. Destratification fans are often used to circulate air through the building volume.

Passive solar heating of specific areas such as loading docks is also feasible.

- Heating of Hot Water and Air

Many low temperature daytime industrial process applications are possible: virtually any industry which requires hot water, air, or other fluids is a candidate for active solar systems, particularly on a direct use basis (without storage). Active solar water pre-heat systems have been installed for bakeries, film processing, car washes, bottle washing, commercial laundries, laundromats. etc. Active solar systems have also been used to pre-heat air for drying processes such as concrete block drying, carpet cleaning, etc. Large flat roof areas are generally able to accommodate solar collectors.

### 3.2 (b) Specialized Industrial

Specialized and heavy industrial buildings are often large volume structures, 2 000 $m^2$ and more in floor area, in steel construction. They may have large roof areas, not necessarily flat, but configured to house industrial processes.

Many heavy industrial processes such as steel making, glass manufacture, metal refining, etc. have major power demands, and produce substantial amounts of excess heat. Space conditioning needs are for the cooling, or disposal of this heat.

- Space Heating

Solar systems for space heating are probably not applicable, as substantial heat is generated by industrial processes.

- Hot Water

Active solar hot water systems may be physically feasible, depending on roof configuration. However, heat recovery from other processes is likely to be more economical.

## 3.3 Commercial

### 3.3 (a) Low and Medium Rise Offices

New small office buildings are 1 000 $m^2$ or more in floor area, 2 to 5 storeys in height, in reinforced concrete or steel frame construction.

Office buildings consist of two zones: a central zone insensitive to climate and subject to cooling load year-round (because of internal heat gains from lights, equipment, people, etc.); and a climatically-sensitive exterior zone, subject to heating or cooling needs, depending on the time of day and year, orientation of the exterior wall, and internal heat gains. In fact, office building exterior walls with large glass areas tend to act as large scale solar collectors, and mechanical designs to make use of this heat energy and to transfer it to locations in the building where it is needed, are quite sophisticated. An essential design problem is to minimize glazing on east and west building faces, to control heat gains which can strain mechanical equipment at certain times of the day and year.

- Space Heating

Since the predominant energy requirement for space conditioning is for cooling, solar systems are not applicable. Some control on glass areas and shading of certain faces of the building may be necessary to control excessive solar gains.

- Hot Water Heating

Although most office buildings have a limited need for hot water, peak demands occur during the day, and roof-mounted active solar systems for direct use may be feasible, if roof area is available.

### 3.3 (b) High Rise Office Buildings

High rise offices are generally 10 storeys or higher, 10 000 $m^2$ or more in floor area, in reinforced concrete or steel frame construction.

As with low-rise offices, high rise buildings consist of climatically sensitive exterior zones and climatically-insensitive interior zones. Much of the exterior skin is glass; building faces tend to act as solar collectors at different times of the day. Mechanical systems are usually designed to transfer heat gains (solar, people, lights, etc.) to supply the heat loss areas of the building. These areas will shift during the day.

Hot water demands are not large, but occur during the day.

- Space Heating

As with low rise office buildings, solar systems for space heating are probably not applicable.

- Hot Water Heating

Active solar systems mounted on the roof are only feasible if there is sufficient demand, and unshaded roof area is available. The latter may be difficult to control in high density urban areas. Conventional hot water systems will also be necessary.

Again, vertical, unshaded south wall areas may be possible for collectors, but these would operate at a lower efficiency than roof-mounted collectors.

### 3.3 (c) Hotels

Hotels are 10 000 $m^2$ or more in floor area, usually in medium to high rise reinforced concrete construction. Interior spaces include hotel rooms, assembly spaces such as dining, lounges, meeting rooms, swimming pools, etc., and service areas such as kitchens, laundries, storage areas, loading docks, parking garages, etc.

Hotel spaces have different conditioning requirements depending on their function: hotel rooms require air conditioning (cooling in summer, heating in winter); public spaces are climatically insensitive, do not need sunlight, and generate cooling load; service spaces (kitchens, laundries, etc.) also generate cooling loads year-round.

Hotels also need substantial amounts of hot water, particularly in the morning.

• Space Heating

Waste heat recovery from heat-producing spaces (kitchens, assembly rooms, laundries, etc.) can be used to supply heat-requiring spaces such as guest rooms, when required. This may be only in certain locations, and at certain times of the year. In most instances, this will probably be more economical than solar systems.

• Hot Water

With substantial daytime hot water demands, active solar, roof-mounted systems for direct use are feasible, as a back-up to conventional hot water systems (which are necessary to supply peak demands).

Active solar systems to heat interior or exterior swimming pools are feasible if site or roof collector area is available.

## 3.4 Retail

### 3.4 (a) Shopping Centres

Shopping centres in suburban areas are often 10 000 $m^2$ or more in floor area, usually one (but no more than two) storey(s) in height, in steel joist construction, with blank (non-glazed) external wall areas.

With their high occupant loads and few windows (roof top skylights being the general exception), shopping centres have year-round space cooling requirements. Most stores will not have significant hot water demands, although certain functions such as dishwashing in restaurants, or laundromats, will be exceptions.

• Space Heating

Solar systems are not applicable.

• Hot Water

It is usually possible to install solar collectors on large flat roof areas, but low hot water demands probably make it unnecessary. Specific uses within a shopping centre may have substantial domestic hot water needs which could be partly supplied by local collectors.

### 3.4 (b) Single Use Retail Buildings (Restaurants, Supermarkets, etc.)

Individual buildings are single storey, light steel frame construction, 1 000 $m^2$ or more in floor area, with large adjacent asphalt parking areas.

Heating and cooling demands depend on the particular use: many building types (supermarkets, restaurants, etc.) require cooling only, because of their merchandise requirements for cooling, as well as high heat gains generated internally (for example, from high lighting levels).

Hot water needs, except in restaurants, are probably limited.

• Space Heating

In most building types, passive solar design is probably unfeasible because of the potential for merchandise deterioration. Display windows and seating areas cannot tolerate direct sunlight and solar heat gain. If heating is required, recycling from internal heat sources (for example, the refrigerated displays and lighting in supermarkets) is likely to be the first choice.

• Hot Water

For stores with limited hot water requirements, hot water heating is probably best supplied from conventional sources or heat reclamation from internal heat sources.

For uses with high domestic hot water demands (such as laundromats, restaurants, etc.), use of active solar systems in direct use, pre-heat applications, may be feasible.

## 3.5 Public Buildings

### 3.5 (a) Hospitals

New urban hospitals generally exceed 10 000 $m^2$ in floor area, and are 3 to 5 storeys in height. Both reinforced concrete and steel frame construction are common. Hospitals include a number of rooms with specialized demands, such as patient rooms, operating rooms, laboratories, kitchens, cafeterias, laundries, etc.

Patient rooms require air conditioning, with some heating in winter. No mass air flows are permitted between patient rooms. Hospitals also have a large number of high humidity, heat-producing areas, as mentioned above. Some of these specialized areas (laundries, kitchens, operating rooms) have substantial hot water needs.

• Space Heating

In general, passive solar design is not feasible: direct gain and bright sunlight are unacceptable in patient rooms. Solaria at the south ends of patient floors are common in older hospitals, and are a desirable feature. Specialized rooms, such as operating rooms and laboratories, generally have no windows, or are designed to restrict or control daylight when required.

Active solar systems for space heating are unlikely to be as economical as heat recovery from heat-producing areas.

- Hot Water

Many specialized areas have heavy daytime hot water needs. Active solar systems backing up conventional and waste recovery hot water heating, are increasingly feasible economically.

### 3.5 (b) Schools

New school construction is usually light steel frame, one to two storeys in height. Schools range from 2 000 to 3 000 $m^2$ in floor area. Secondary schools, with larger student populations, may be much larger.

Classrooms and specialized areas (laboratories, gymnasia, auditoria, service spaces, etc.) require heating or cooling, depending on the time of year, and internal heat gains from occupants, lights, etc. (which will vary during the day).

- Space Heating

Passive solar heating is possible for classrooms, if considered in conjunction with daylighting requirements. Students cannot be in direct sunlight, and classrooms may need black out for certain activities. Trombe wall and thermo-siphon assisted heat pumps may be feasible design solutions.

Active solar systems are also feasible if a large, appropriately oriented roof collector area is available, and thermal storage can be integrated into the design. Active solar systems are unlikely to be as economical as passive systems for space heating.

- Hot water

Certain functions, particularly physical education and laboratories in secondary schools, have daytime hot water demands, for which active hot water heating systems for direct use are feasible.

### 3.5 (c) Assembly (Theatres, Stadiums, Arenas, Churches, etc.)

Assembly buildings generally exceed 1 000 $m^2$ or more in area, and are large span structures, often in steel or wood, climatically insensitive (with small window areas).

They are subject to sporadic use by large numbers of people, often in the evening. When empty, they have low heating requirements, even in winter; when occupied, they generate peak cooling demands after several hours of use.

Hot water demands are nominal.

Table 1: Applicability of Solar Energy to Building Types in Ontario

| | DEMANDS | | | SYSTEM APPLICABILITY | | | COMMENTS |
|---|---|---|---|---|---|---|---|
| | Space Conditioning | | Hot Water | Space Conditioning | | Hot Water | (Where * Noted) |
| | Heat | Cool | | Passive | Active | Active | |
| 3.1 Residential | | | | | | | |
| a) Single Family Detached | O | | O | O | O | O | |
| b) Attached Multiple | O | | O | O | O | O | |
| c) Low Rise Apartments | O | | O | | O | O | |
| d) High Rise Apartments | O | | O | | O* | O* | Site or roof area may not be large enough for collectors |
| 3.2 Industrial | | | | | | | |
| a) Low Rise Industrial | O | | O | O | O | O | |
| b) Specialized Industrial | | O | O | doesn't apply | | O* | Use of waste heat may be cheaper |
| 3.3 Commercial | | | | | | | |
| a) Low - Medium Rise Offices | | O | O low | doesn't apply | | O | |
| b) High Rise Offices | | O | O low | doesn't apply | | O* | Probably insufficient roof area |
| c) Hotels | O | O | O | | | O* | Use of waste heat may be cheaper |
| 3.4 Retail | | | | | | | |
| a) Shopping Centres | | O | O low | doesn't apply | | O* | Low water demand |
| b) Single Use Buildings | | O | O | doesn't apply | | O | |
| 3.5 Public | | | | | | | |
| a) Hospitals | O | O | O high | doesn't apply | O | O* | High water demand |
| b) Schools | O | O | O | O | O | O | |
| c) Assembly | | O | | doesn't apply | | | |
| d) Other | O | O | O low | O | O | O | |
| 3.6 Other Types | | | | | | | |
| a) Mixed Use Complexes | | O | O | | | O* | Use of waste heat may be cheaper |

• Space Heating

Active solar systems have been installed in some assembly buildings such as churches, to assist in winter space heating, which is necessary even when buildings are unoccupied. Retrofit applications in existing buildings which are difficult to insulate and expensive to heat (such as churches) may also become more common. Integration of solar collectors with large span roof structures will be important.

• Hot Water

Limited demand.

3.5 (d) Other Public Buildings (Police Stations, Libraries, Fire Halls, etc.)

These are small one and two storey buildings, 500 $m^2$ and more in area, in a variety of construction types such as steel, wood, reinforced concrete, masonry bearing wall, etc.

Small floor areas, relatively low (but continuous) occupant loads, and relatively large window areas make many buildings in this category climatically sensitive. Space conditioning requirements will vary with the season, time of day, and wall orientation.

Hot water needs are generally low.

• Space Heating

Passive and active solar systems may be feasible if integrated into building design. Solar assisted heating of particular rooms is also possible: for example, fire hall hose drying towers, equipment and pump rooms.

Direct sunlight into some buildings such as libraries is unacceptable, but Trombe wall and other passive designs may be possible.

• Hot Water

Solar assisted domestic hot water is probably unnecessary, due to generally low demands. There may be some exceptions to this.

3.6 Other Building Types

3.6 (a) Mixed Use Buildings (Offices, Retail, Apartments)

Such building complexes often exceed 10 000 $m^2$ in floor area, are 5 to 10 storeys in height, with combinations of steel frame (offices, retail) and reinforced concrete (parking garages, apartments, possibly offices) construction.

Each separate component in a mixed use complex has distinct heating and cooling requirements: offices require cooling year round, as does retail space; apartments require heating or cooling depending on the season, as well as hot water, year round.

- Space Heating

The most economical space heating strategy in large building complexes is to extract waste heat from the cooling systems employed at several locations in the project for transmission to areas requiring space heating.

In a high density complex it may be difficult to locate sufficient unobstructed roof area for solar collectors, although surface parking lots and garages, or landscaped areas may offer some room.

- Hot Water

Apartments have major hot water demands. Heat pumps using excess heat from other parts of the project are attractive options for assisting hot water heating. Active solar systems for domestic hot water, and other specific uses such as laundries, swimming pools, restaurants, etc. may also be economically feasible if unobstructed roof areas are available.

# 4. LAND USE IMPACTS

## 4.1 Introduction

Small solar energy units attached to, or located near, individual buildings, industries, or groups of buildings, are potentially important additions to the limited opportunities for increasing Ontario's energy supply. In order for solar energy to be used, it must be received by collectors, which in turn, must be given unimpeded access to the sun. Reduced to its most essential terms, land use planning for solar access is concerned with the spacing of collectors so that they receive the sun without being blocked by shadows from buildings or other objects in the landscape. Devices to store the energy received can generally be integrated with building construction at or below ground level.

This section discusses how the requirements for spacing collectors interact with conventional community design criteria for the arrangement of buildings, lots, and roads. It also discusses the environmental, social, and land cost impacts of collectors and solar energy systems, and the tradeoffs with which municipal planners may be faced.

### 4.1 (a) Centralized vs. Dispersed Solar Systems

There are no clear economies of scale in solar collectors, solar cells, or in many types of engines compatible with solar energy, although there are economies of scale in many kinds of energy storage (at least up to a scale where they are capable of storing enough energy for several hundred typical residences). Collectors are also distributed because the solar resource is distributed, but storage devices could be aggregated or centralized for certain applications.

However, on-site (dispersed) collectors also have some limitations. As density increases, few opportunities for non-rooftop collection are available. If roof angle and orientation cannot be adapted to accommodate collectors without prohibitive cost, if insufficient surface area is available for collectors, or if available roof or ground space is shaded by neighbouring structures, an on-site solar system would not be feasible. If 40 $m^2$ of collector area were required for each 120 $m^2$ apartment unit, then there would only be roof area on the building to supply 3 storeys of units. In some cases, existing mid- and high-rise structures are surrounded by parking lots which could be covered with collector roofs to increase available collector area.

New high-rise structures can be designed to incorporate solar collectors into walls as well as roofs, where adequate open space around the structure allows for access to sunlight. In high density areas with many high rise structures, on-site solar systems will probably be unfeasible in many cases.

In existing neighbourhoods, many houses may not be located or oriented for optimum placement of collectors. Arguments can be made for aggrega-

ting collectors under certain conditions; i.e., if there is surplus land available, some form of communal ownership and maintenance, and collectors can be protected from vandalism (as they can be on building roofs).

In new low-density subdivisions, individual collectors are the most probable configuration because buildings can be oriented and spaced for individual solar access. Even in new development areas, other planning criteria may take precedence over solar access criteria, and centralized collectors may then be considered (to reduce the problem of providing solar access for every individual site to providing it to a few "collector" sites).

An economic analysis of centralized solar systems must balance potential savings from larger scale collector or storage systems against the added capital and operating costs and losses for distribution lines from the central facility to individual users. These distribution costs are proportionately less for electrical systems than for thermal systems, and consequently, there is generally more freedom to locate photovoltaic collectors independently of buildings than there is, for example, with solar thermal systems.

Other conditions for a centralized solar system include:

- communal ownership and development of the system,
- compact clustered development to minimize distances from the collector and/or storage to individual units, and
- a lot large enough to ensure optimal collector placement and protection.

The situations in which all of these conditions will be favourable are relatively few in number, and it is expected that dispersed (individual) solar systems will predominate in the near future.

Where conditions do tilt the balance in favour of the separation of solar components from the point of use (as with some solar electrical installations), collectors can make use of underutilized spaces and land areas such as surface parking lots, utility and transportation corridors, recreation areas, and flat roofs.

In outlying and rural areas, such collector arrays could be located remotely (permitting use of less expensive lands, but increasing transportation costs) or close in to the community or industry served, opening up the possibility to generate thermal as well as electrical energy, but increasing land costs and competition among land uses. In any case, the collectors should be located on lands less favoured for agriculture or high-priority urban uses.

Until the economics and feasibility of centralized solar systems become more favourable, and the limits on both the availability and suitability of underutilized and vacant urban spaces are understood, it is difficult to make provisions for them in community plans, except in specific instances. However, the time may come when large solar collector arrays may have to be considered as a land use category in their own right, competing for the same scarce land resource as other urban activities.

## 4.1 (b) The Need for Solar Access

Specific provisions for solar electrical systems and centralized solar systems may be some time away. However, in the near future, municipal planners should be concerned with solar thermal systems integrated with the individual buildings they serve. Certain building types, though, have space or water heating needs which cannot be economically served by solar systems. These include:

| | |
|---|---|
| • high rise apartments | substantial hot water demands, but limited roof areas for collectors (unless vertical wall areas can be made available) |
| • high rise offices | largely cooling load, limited hot water needs and roof area for collectors |
| • hotels | generate waste heat which can be re-used; some solar potential for hot water heating |
| • specialized (heavy) industry | generate waste heat which can be re-used |
| • retail | largely cooling needs, limited hot water demand except in certain instances (which can be met by local collectors) |
| • assembly | largely cooling load when in use |
| • mixed use development | generate waste heat which can be re-used; some solar potential for hot water heating. |

Also, other land uses and building types can usually make use of solar access, but some of them only need a limited form of it. Solar access can be defined in three ways: (Figure 23)

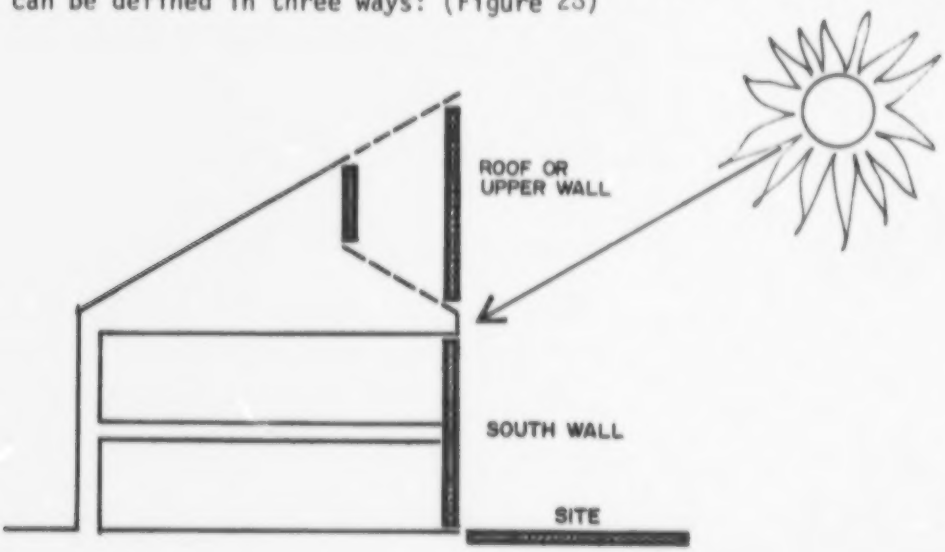



Figure 28 Types of Solar Access

- Site Access to a ground plane adjacent to (south of) a building, to reflect solar energy into the building, or to accommodate solar collectors not directly attached to the building;

- South Wall Access, applicable to most passive solar installations, or active solar systems where roof areas are limited and wall areas must be substituted;

- Roof Access: applicable to active solar collectors on roof areas.

The most restrictive form of solar access is site access, since space must be provided on the lot, not only for the building, but for solar collectors to the south of the building (so that they are not shaded by it). If the lot is large, there may be greater freedom in placing collectors not directly attached to the building. Large lots are of less concern to the municipal planner because they can generally be planned comprehensively.

Site access is usually restricted to applications such as residential swimming pools (which require large lots in any case) and remote collector systems. Large building complexes such as hospitals, universities, schools, etc. are often located on large lots which permit some flexibility in locating collectors and buildings.

Roof Access is the least restrictive form of solar access. Certain buildings such as low-rise offices, industrial buildings, and apartments often have large roof areas available for collectors. The roof essentially acts as a ground plane one or two storeys above grade.

Passive solar systems for the space heating of low and medium density housing and other small buildings generally require south wall access for large glass areas. Since residential is usually the largest single land use in most communities, south wall access, if adopted for individual buildings, could become a major determinant in the form and arrangement of a community, particularly its suburban areas.

The applicability of different types of solar access to the building types,discussed in Chapter 3, is summarized in Table 2.

## 4.1 (c) Shadow Impacts

With Ontario's low winter sun angles, buildings in excess of one storey cast long shadows, possibly blocking solar access to nearby buildings. This is not important in rural areas where buildings are spaced far apart, but may be a major concern in urban areas with built-up development lots in close proximity.

The severity of this impact is related to factors such as the size of the lot, the height of the building (including the collectors on top of it), and the requirements of nearby buildings for solar access.

Table 2: Off-Site Impact and Solar Access Needs for Building Types in Ontario

| | SYSTEM APPLICABILITY | | TYPE OF SOLAR ACCESS NEEDED | | | POTENTIAL OFF-SITE SHADOW IMPACT |
|---|---|---|---|---|---|---|
| | Passive | Active | Site | Wall | Roof | |
| 1. Residential | | | | | | |
| a) Single Family Detached | ○ | ○ | ○ swim. pool | ○ | ○ | moderate |
| b) Attached Multiple | ○ | ○ | ○ swim. pool | ○ | ○ | moderate |
| c) Low Rise Apartments | | ○ | | | ○ | moderate |
| d) High Rise Apartments | | | | | | major |
| 2. Industrial | | | | | | |
| a) Low Rise Industrial | ○ | ○ hot water | | ○ | ○ | little |
| b) Specialized Industrial | | | | | | little (on large sites) |
| 3. Commercial | | | | | | |
| a) Low - Medium Rise Offices | | ○ hot water | | | ○ | moderate |
| b) High Rise Offices | | | | | | major |
| c) Hotels | | ○ hot water | | | ○ | moderate |
| 4. Retail | | | | | | |
| a) Shopping Centres | | | | | | little |
| b) Single Use Buildings | | ○ | | | ○ | little |
| 5. Public | | | | | | |
| a) Hospitals | | ○ hot water | ○ rem-ote | | ○ | moderate |
| b) Schools | ○ | ○ hot water | ○ rem-ote | ○ | ○ | little (on large sites) |
| c) Assembly | | | | | | moderate |
| d) Other | ○ | ○ | ○ rem-ote | ○ | ○ | moderate, depending on building and site |
| 6. Other Types | | | | | | |
| a) Mixed Use Complexes | | | | | | major (usually high density) |

In high density office zones, the effects of sunlight blockage on adjacent office buildings may not be severe, since these nearby buildings probably have little use for solar access. However, other public objectives may support sunlight access to the sidewalk or street in order to improve the pedestrian environment.

Several kinds of criteria can be adopted for shadow impacts: (Figure 29)

- confining all shadow impacts of the building and its collectors to the development site itself. This may be acceptable in rural areas, but is probably unreasonable in urban areas. It is probably feasible for certain low-rise buildings on large sites, such as industrial, schools, and shopping centres.

- confining the shadow impact to the shading of public streets and sidewalks. This may be unreasonable in high density office zones where a street canyon effect, always in shadow, may be created.

- permitting shadow impacts on public parks and open space areas.

- permitting shadow impacts on the setback zone of adjacent lots. This may be a problem if the setback zone of the adjacent lot is also the outdoor living area for a housing unit. However, shadow impacts are longest in the winter, when such outdoor spaces may be less used. In summer, with higher sun angles, such outdoor spaces would probably be in sun for most of the day.

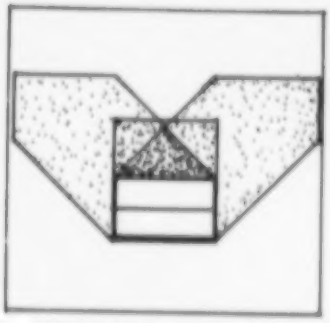
The definition of criteria for shadow impacts in turn helps to determine how far apart buildings can be spaced. More restrictive criteria imply lower densities, less restrictive criteria permit closer spacing of buildings and, therefore, higher densities.

### 4.1 (d) Topography

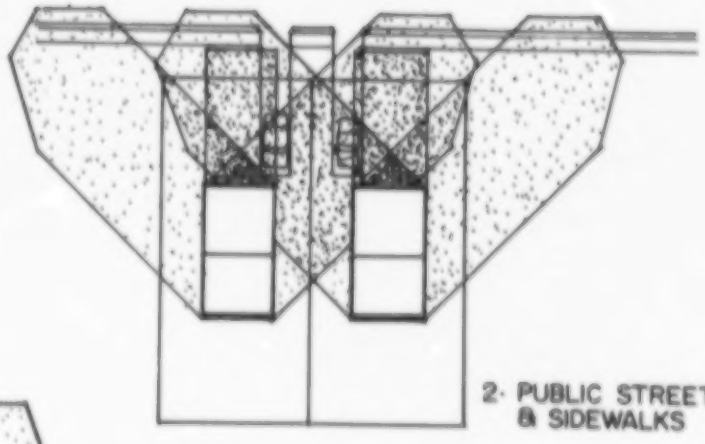
Solar access may not be applicable to certain landforms, such as steep north-facing slopes. Shadows shorten with favourable south slopes (in comparison with flat sites), but lengthen with unfavourable north slopes (Figure 30).

Depending on local planning regulations, such steeply sloping lands may be restricted for building in any case, and designated instead for other uses such as ravine parkland. Residential development on steep sites could block solar access to sites below.

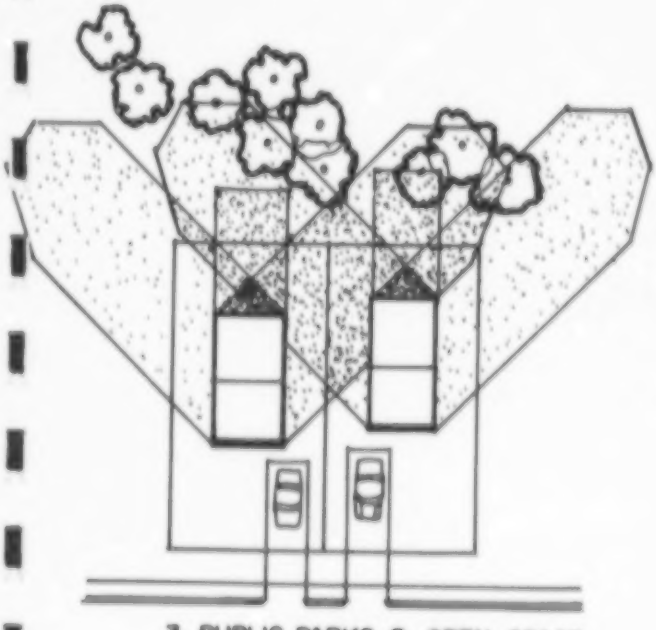
# Figure 29 SHADOW IMPACTS



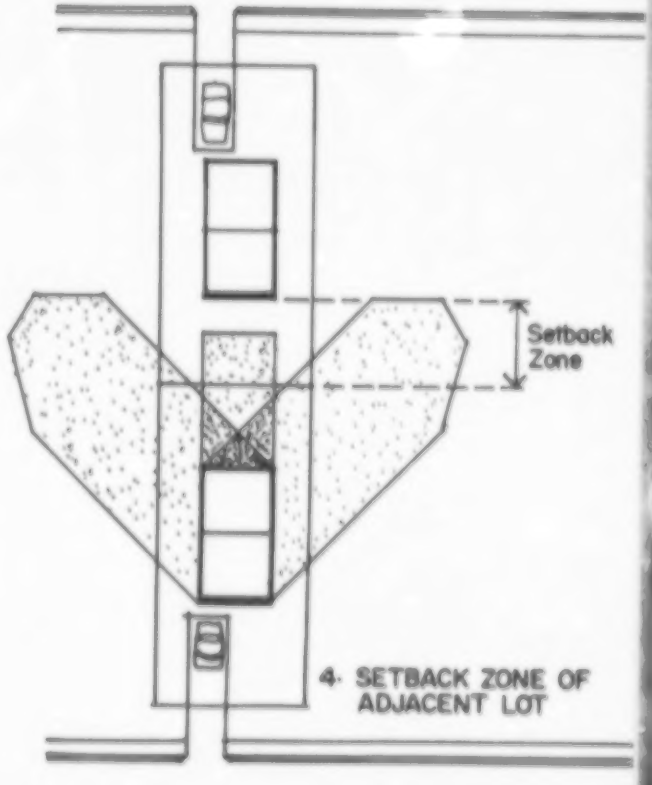
1. DEVELOPMENT SITE



2. PUBLIC STREETS & SIDEWALKS



3. PUBLIC PARKS & OPEN SPACE




4. SETBACK ZONE OF ADJACENT LOT

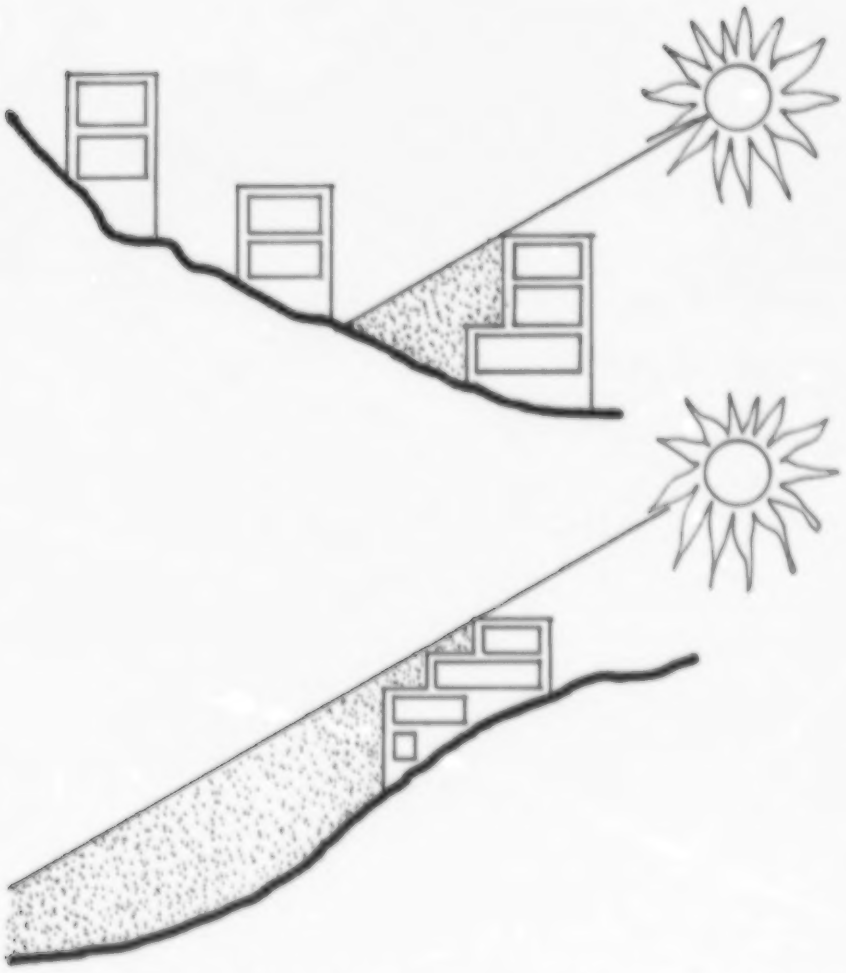


Figure 30: The Effect of Land Slope on the Amount of Area Shaded by a Building.

## 4.2 Residential Solar Potential

Built-up residential neighbourhoods may comprise 40% or more of a community's land area and are usually its largest single land use. While the solar potential of these neighbourhoods (in terms of the houses and buildings which can be affected) is large, it may be severely compromised by existing conditions.

New neighbourhoods represent an opportunity to shape community design to accommodate solar systems (particularly their collectors), but even in cities undergoing rapid development, constitute no more than 1 to 3% of the city's housing stock. Thus, the shaping of an urban area to accommodate solar systems may take many years, affecting only the housing stock built after the adoption of solar planning criteria. The solar potential of new areas is theoretically unlimited, but the number of houses which can be affected is small. Over time, this number can increase, as annual additions to the community's housing stock are made.

To the municipal planner, the distinction between built-up and new development areas is important because solar potential is different in each case.

## 4.2 (a) Built-Up Neighbourhoods

Built-up neighbourhoods generally have some restrictions on the potential for solar access. Certain characteristics of an existing urban pattern affect this potential:

- the size, orientation, spacing, and shape of the street layout
- lot sizes, shapes, and orientations
- topography
- land use
- development controls which influence to some degree, the shading of buildings by nearby buildings.

Developed residential areas, particularly those which have matured over a number of decades, are often fairly stable, with development densities at or near the limits of present zoning by-laws. Therefore, the most prevalent form of development which might have a solar system component is retrofit, i.e. incremental changes to existing buildings, which do not substantially alter the external form or density of the neighbourhood. This retrofit potential will be subject to the economic and structural limitations of existing buildings, as well as the purposes and needs of their present owners.

Existing land use patterns often ignore topography and climatic conditions. Most pre-war street layouts were geometric grids. Certain cities have a relatively favourable east-west grid orientation, such as Vancouver; other cities such as Toronto, have a less favourable north-south grid orientation (based on its historical development north from Lake Ontario). Subsequent post-war suburban development with curvilinear streets and lots for housing and industry, have continued a tradition of ignoring the sun. Also, existing structures and vegetation, whether in pre-war grid, or post-war curvilinear development, may restrict solar potential, but cannot be altered substantially. Therefore, a principal land use planning goal in existing neighbourhoods should be the maximization of the solar potential which remains.

There are several mitigating factors to this complex situation:

- there are a number of generally favourable urban locations for receiving unrestricted sun, such as the north side of east-west streets, and the north side of public parks, river edges, lakeshores, etc.

- there are a number of generally favourable locations where long shadows can be cast, such as the south side of east-west streets, and the south side of public parks, rivers, lakes, etc. (This may provide some flexibility in modifying building heights and roof profiles to accommodate solar collectors);

- certain lotting arrangements are more favourable than others for the placement of solar collectors: (Figures 31, 32)

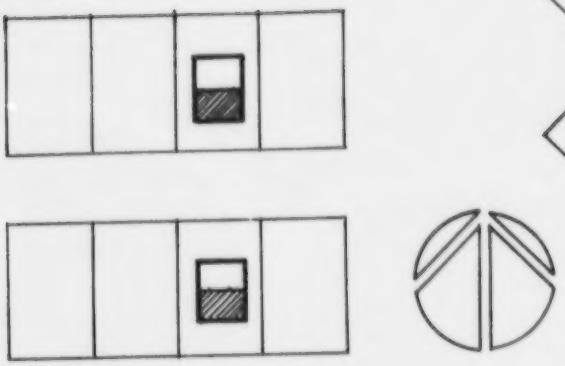


Figure 31:

Favourable Orientation:
East-West Streets

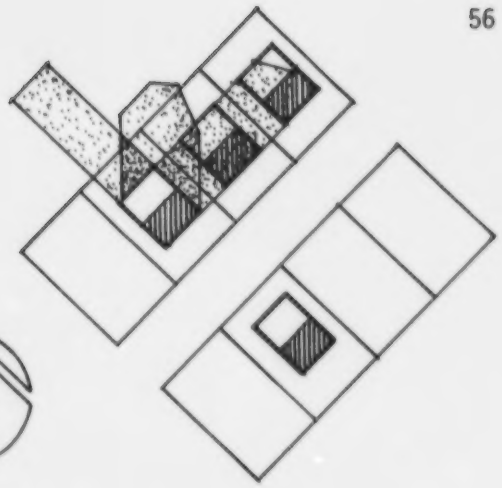


Figure 32:

Unfavourable Orientation:
Intercardinal Small Lots

- Buildings with large roof areas or large lot areas generally have sufficient space to site collectors appropriately: (Figures 33, 34)

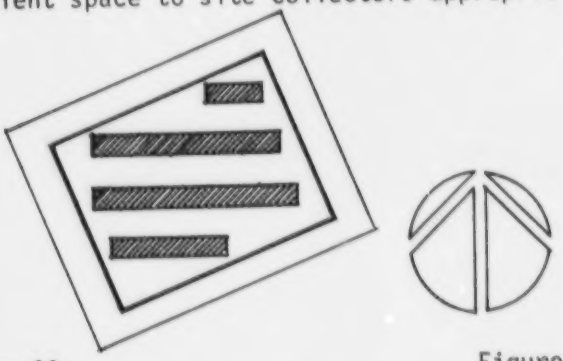


Figure 33:

Large 1 Storey Industrial
Roof for Collectors

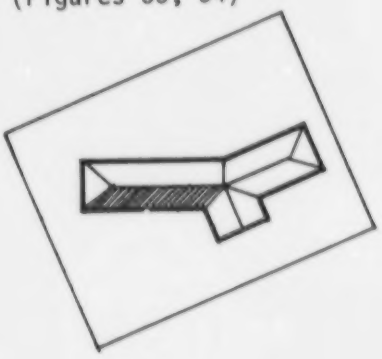


Figure 34:

Large Residential Lots Permit Some
Portions of a Roof to Face South

- Certain building types are more adaptable to the placement of collectors than others: (Figures 35, 36)

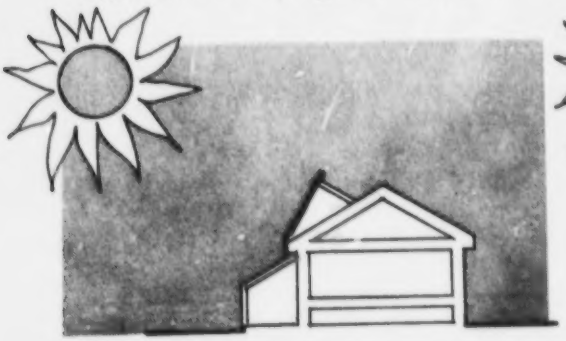


Figure 35:

Typical Suburban House, Low Pitch
Roof

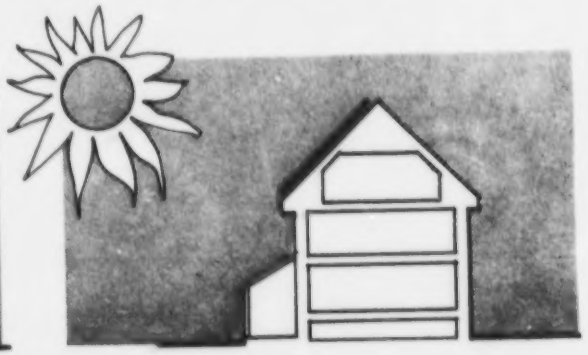


Figure 36:

Higher Roof Slope (Pre-War)

Perspectives on determining solar retrofit potential in a neighbourhood are different for individual property owners and municipal planners. An individual is concerned with the specifics of his site; whether objects in the landscape block his solar access, whether his structure is adaptable to solar collectors, what obligations he may be under in casting shadows on neighbouring buildings and properties.

Since neighbourhoods were not laid out according to solar criteria, the first aspect is one of luck; being located in a favourably oriented building on a favourably oriented lot. If appropriate land use planning regulations are in place, then this luck can be controlled either by municipal authorities, or by the individual owner himself, in objecting to developments which would overshadow him.

The municipal planner is concerned with general solar potential in existing neighbourhoods, first in order to determine whether it exists, and second, in order to encourage and protect this potential. Steps in a process to determine the solar potential of built-up areas are described in Chapter 5: Development Approvals.

### 4.2 (b) New Development Areas

Solar potential is theoretically unlimited in new, undeveloped land areas, restricted only by major vegetation to be retained.

South wall is the form of solar access which has the greatest applicability for residential passive solar installations, although several qualifications should apply to the definition:

- percentage tolerances allowing less than optimal siting of the collector surface (see discussion under 2.1 (a) Performance of Passive Solar Components).
- the angle (altitude) of the sun above the horizon. The sun is only useful above a minimum altitude angle, generally taken to be 10 to $12^{0}$ above the horizon, due to obstructions by trees or other low objects in the landscape, and the filtering of the sun's energy as it passes through layers of atmosphere at low angles. This defines the daylight hours for which solar access is useful, and therefore should be protected.
- whether self-blockage by the building itself should be permitted (i.e., whether the recipient of solar access is under obligations to make the best use of the resource).
- dates for defining critical shadow lengths and impacts. December 21 is the shortest day of the year, with the longest shadows. However, the choice of this date is unduly restrictive since every other day is longer, and January 21 or November 21 are generally taken as the most suitable dates for determining shadow impacts.

The shadows cast by buildings are important determinants in subdivision design for solar access, since they dictate how far apart buildings must be spaced. Figure 37 indicates the shadow patterns for standard one and two storey houses on a flat site at 44° North Latitude (equivalent to Brampton, Ontario). A narrow frontage, deep house will cast a longer shadow than a wide frontage, shallow house of the same floor area. Buildings higher than 1 storey start to cast longer shadows, extending beyond conventional lot depths of 30 to 36 m for housing.

Shadow patterns also have several implications for the design of housing: low roof pitches are preferred for all house types to reduce the length of shadow cast (a fact which may conflict with the preferred angle for the mounting of a solar roof collector); lower houses cast shorter shadows and allow a closer spacing of buildings than two storey or higher buildings; and the south side of a house can be as high as required within critical shadow angles.

Shadow patterns dictate the minimum spacing of buildings no matter what street orientation is used. All street directions are possible with solar access, but different urban design issues arise in each case:

- with north-south streets, long shaow patterns could lead to excessively wide lot frontages, therefore strategies such as "flag lotting" are used to increase the number of houses in a given length of street;
- with east-west streets, houses on the south side can be higher (2 to 3 storeys) since they cast shadows on the street; north side houses should be low and have integral garages. Houses on both sides of the street can have slightly varying setbacks from the street while maintaining unimpeded solar access; (Figure 38)
- with non-cardinal (other than E-W or N-S) streets, other strategies such as parallelogram lots may be necessary.

Housing form and subdivision layout must be considered together if solar access is to be accommodated in new development areas. The very purpose of a subdivision lotting plan to accommodate solar-responsive houses can be defeated if the houses themselves are not designed to take advantage of this resource.

Some general principles for solar-responsive housing include:

- minimize the amount of north side glass.
- provide south side glass areas to optimize the required amounts of passive solar gain.
- provide for thermal storage in the walls, floors, or basement of the house, related to the solar wall.
- in passive solar design, roof shapes should have low slopes, and where feasible, be configured to direct daylight and sunlight to all parts of the house. A portion of the south facing roof may be angled to take active solar collectors.

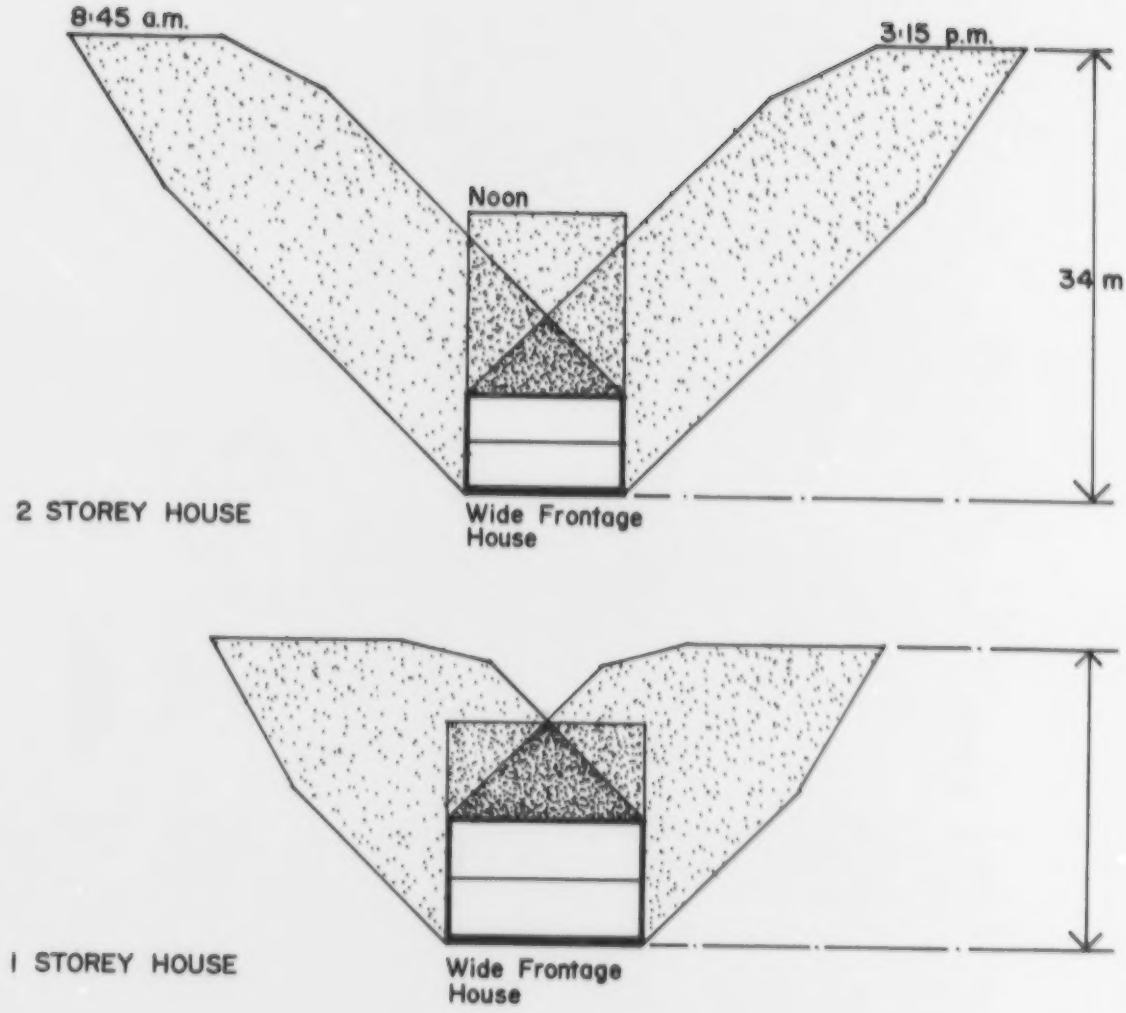



**Figure 37**
**COMPARATIVE SHADOW PATTERNS**
44° NORTH LATITUDE
DECEMBER 21

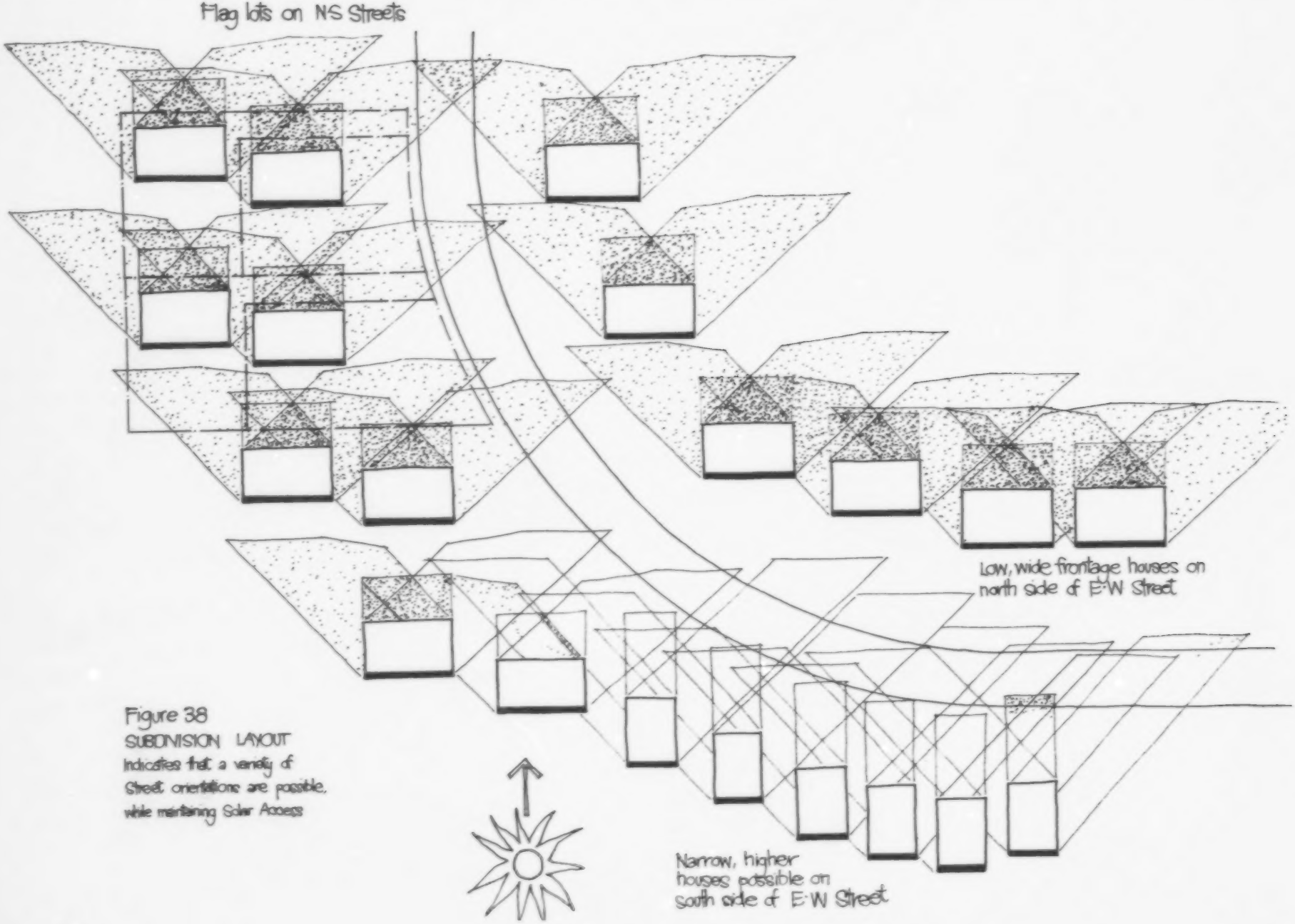

Flag lots on N-S Streets
Low, wide frontage houses on north side of E-W Street
Narrow, higher houses possible on south side of E-W Street

Figure 38
SUBDIVISION LAYOUT
Indicates that a variety of Street orientations are possible, while maintaining Solar Access

- living spaces should be placed to the south side of the house, together with adjacent outdoor areas; service spaces should be to the north side of the house, where feasible.
- the north side of the house should be as low as possible, while the south side of the house can be as high as desired within the specified shadow angles.
- no part of the house plan should project farther south than the solar wall, unless it is below the solar wall.

Corresponding principles for subdivision layout (assuming that lots must be laid out in advance of house design and location) include:

- zero lot line zoning: allows maximum freedom in placing houses on each lot in the most advantageous positions for solar access.
- efficient subdivision layouts for solar access are probably encouraged by lot lines oriented along the cardinal (compass) directions.
- houses should be placed on lots so as to cast shadows on road allowances wherever possible.
- wide frontage (to the south) and deep (to the north) lots offer the greatest flexibility in placing houses appropriately within the lot boundaries, while still maintaining solar access. If the house location is not determined in advance of lotting, the best lot shape for such flexibility may be close to a square. If the basic house shape, solar wall, and location, can be fixed by the appropriate legislative tools while the subdivision plan is still being prepared, then smaller and narrower lots may be feasible.

## 4.3 Industrial Solar Potential

Most recent (i.e. post-war) light industrial buildings are one storey in height, and located in suburban areas. In many communities, the earlier multi-storey industrial structures have been demolished or renovated to other uses. Multi-storey industrial buildings may continue in operation, but are less adaptable to the loads and flows of modern industrial equipment and processes.

In either case, the primary requirement for solar equipment is likely to be for roof top collectors for the heating of water, fluids, or air for industrial processes, for which roof access will be sufficient. Therefore, the distinction between retrofit (existing buildings) and new development is not as sharp as in residential, because both types generally have large roof areas, are capable of supporting collectors, and are unlikely to be shaded by nearby buildings or vegetation.

## 4.3 (a) Built-Up Areas - Retrofit Applications

Solar collectors are fairly lightweight structures and can usually be placed on a flat roof in the correct orientation. This may not align with the existing structure below, possibly necessitating some structural adjustments.

Projecting collectors will increase the apparent building height, and may require a zoning variance in areas of restricted building height. Roof top collectors should also not be placed to cast additional shadows on adjacent buildings.

Solar potential may be affected in older multi-storey industrial areas, where buildings have a variety of heights, but on buildings with large roof areas, collectors can usually be placed to avoid overshadowing. This should not be a problem in low density (one storey ±) post-war industrial parks.

## 4.3 (b) New Development Areas and Buildings

Buildings are generally placed parallel to the lot lines. Therefore, if lot boundaries can be rectangular and oriented east-west and north-south, it will offer the greatest opportunities for alignment of collectors with structure. If lots are large enough, building and collector shadows should be confined within the lot lines; this will require setbacks at least equal to building height.

Buildings requiring solar access should probably be aligned east-west, thus presenting a long south face, and a roof and column structure aligned with the preferred collector orientation. However, this is not a firm rule, since many retrofit installations have been undertaken without perfect alignment to the underlying column structure.

Buffer and setback areas should be provided between zones of different densities, so that the buildings in the higher density zones do not cast shadows on buildings in the lower density zones.

## 4.4 Commercial (Retail, Offices, Hotels)

Roof, wall, or site access for collectors may be required, depending on the particular application. The most prevalent solar equipment need will probably be for solar collectors heating hot water, fluids, or air, for which roof access will be needed. Site access will probably only be useful on large lots (for example, resort hotels) and is unlikely to be feasible in urban areas.

## 4.4 (a) Built-Up Areas - Retrofit Applications

The downtown commercial areas in many Ontario communities have 2 to 3 storey brick structures of architectural character. The streetscape of such areas is important to community identity, and many have been upgraded with tree planting, pedestrian lighting, and storefront rehabilitation.

The retrofitting of such buildings with solar collectors brings with it a sensitive issue of how they can be integrated with building facades. Arrangement of roof collectors so that they are hidden from view at street level, is likely to be preferred to concealment behind new roof top enclosures which may not harmonize with the building.

Large existing roof areas may permit collector installation so long as they are not shaded by other parts of the building complex or by nearby buildings. Large roof areas are also useful for solar collectors because they are not accessible to vandals.

As with industrial retrofit, projecting collector arrays will increase the building height, and may require zoning variances. They should also not be placed to cast additional shadows on adjacent buildings.

## 4.4 (b) New Development Areas and Buildings

The alignment of roofs, buildings, and lot lines, in an east-west and north-south direction allows the greatest potential to align collectors properly, close to structural supports, and without wastage of roof area. Buildings should be placed on a site so that collectors are not shaded by other buildings nearby.

High building portions placed to the north side of the site will allow maximum solar access within the site, but care should be taken not to shade adjacent properties.

Solar collectors can also be placed on other parts of the site (for example, parking lots) if they are not shaded, or accessible to vandals.

## 4.5 Public, Recreational, and Other Building Types

Roof, wall, or site access may be required, depending on the particular application. As with commercial buildings, the most prevalent need will be for roof access for hot water solar collectors.

Site access will apply only on large sites, and in rural locations.

## 4.5 (a) Built-Up Areas - Retrofit Applications

Integration of solar collectors with existing heritage buildings will be particularly important. If this cannot be accomplished with sensitivity or concealment, then solar collectors may not be feasible.

As with industrial applications, collectors are lightweight structures, and can be placed on most flat roofs in the correct orientation, even if out of alignment with the structure below, without severe detrimental effects.

Projecting collectors will increase apparent building height, and may need a zoning variance in areas of restricted building height. Also, collectors should not be placed to cast shadows on adjacent buildings.

## 4.5 (b) New Development Areas and Buildings

Larger sites need not necessarily have a cardinal (compass direction) orientation, but the boundaries of smaller sites should have a north-south or an east-west orientation. Buildings or parts of them (such as roof areas) should also be aligned in an east-west direction.

Individual buildings in a complex should not shade one another. If roof access is all that is required, this implies that higher buildings and roofs should be placed to the north side of the site; if south wall access is required for passive solar purposes, building alignments will have to be studied to avoid shading of glass areas.

# 5. DEVELOPMENT CONTROLS

## 5.1 General Considerations

In developing a strategy to incorporate the potential for solar utilization into land use planning, municipal planners face a complex task. They must balance considerations of process, political acceptance, and administrative costs, with legal needs for a precise definition of solar access requirements, yet flexibility in responding to development conditions. Some of these include:

- Planning Process
  - legislative flexibility: new development controls should be framed within present municipal powers, preferably as extensions or adaptations to existing legislation.
  - political acceptance: new regulations which would restrict local planning powers, or remove the existing development potential of property owners (through height or density controls, for example) are unlikely to be accepted.
  - administrative: controls which are complex to administer and explain to local developers and property owners, are time-consuming to administer, and add to development costs, will also be resisted.
- Solar Access
  - definitions: the type and purpose of solar access required by each land use in the community should be described in physical terms (such as orientation, tilt, time for which access is needed, etc.)
  - impacts: criteria for permissible off-site shadow impacts (if any) from each land use (building + collectors) should be defined.
  - standards: performance or prescriptive standards for where collectors can be sited on a lot or building, height limits, and aesthetic considerations, including roof profiles and landscaping.
  - protection: securing protection from obstruction once a collector is in place, defining the length of time that certainty is required, obligations to make use of solar access if it is granted, whether protection applies to the actual collector, the entire site, or a specified portion of the site (related to the collector needs of the land use).
- Flexibility
  - technology: controls should be adaptable to evolving solar technologies, particularly in terms of the locations and amounts (areas) of collectors, (for example, the possibility of photovoltaic collectors being erected on underutilized sites which do not make direct use of the energy produced).

- climate: solar access criteria must be tailored to the climatic (sunlight, haze, cloud cover, etc.) conditions of a particular site.

- development potential: controls should not inhibit the redevelopment potential of a site or sites, particularly, the ability to combine sites, assemble lands, or reconfigure building masses to meet other criteria.

In implementing these considerations, municipal planners are further faced with major differences between how built-up neighbourhoods and new development (or major redevelopment) areas can be treated. This distinction is important for residential land uses, but is probably less so for other land uses (such as industrial).

## 5.1 (a) Built-Up Areas

Existing neighbourhoods may have a limited solar potential: streets and buildings are often inappropriately sited, existing buildings and trees, on the site or off-site, may block solar access to a site, but cannot be removed.

Since existing neighbourhoods have zoning by-laws already in place, new solar access criteria should fit within existing legislative arrangements, rather than substitute one form of zoning for another (which would entail a lengthy public involvement process). Still, existing landowners are likely to resist changes which would substantially modify their existing development potential, or would differentially affect some property owners. This might occur because certain sites are inherently favoured by position, either to receive unencumbered solar access, or to have minimal shadow impacts.

It is also difficult to guarantee solar access to a building or site in perpetuity unless contractual arrangements are made between adjoining landowners. Zoning can be modified by legislation or application, and variances granted (for other than solar reasons) which might affect solar access to a nearby site. If solar access were to be guaranteed, there might be a corresponding obligation on owners to make use of this potential. Otherwise, other property owners might complain that their rights were curtailed without advantage or use being made of that curtailment.

A process to determine the solar potential of built-up areas could include the following steps:

1. Define land use zones (including parkland) with little or no need for solar access.

2. Identify landforms (terrain) on which solar access may be compromised.

3. For representative neighbourhoods:
   - determine the needs of representative buildings and land uses for solar access.
   - determine the feasibility of providing solar access by assessing present shadow impacts, as well as hypothetical shadow impacts under the present zoning and building lot arrangements.

4. For the "feasible" neighbourhoods:
   - define the criteria for access in each zone.
   - define the impact controls needed in each zone.
   - choose the appropriate mechanism for development control.

## 5.1 (b) New Development Areas

The situation for realizing solar potential in new development areas is somewhat more flexible than in existing urban areas. The rights of existing property owners are not compromised by solar criteria; in fact, they can readily be made part of the conditions for development approval. Existing structures do not shade lots, although vegetation may be in place. Again, if sites are large enough to be comprehensively planned, retention of some vegetation should not compromise solar access too greatly.

Solar potential is also more complete in new development areas: solar exposure considerations can be integrated into site planning; streets can reflect topography, sites can be laid out to allow some flexibility in locating buildings, shading of adjacent lots can be minimized.

Similarly, new regulations are less encumbered by existing legislation: a variety of techniques is available; new regulations can define solar access zones, uses, performance standards, design principles.

As in retrofit (existing areas), certain land uses have a limited need for solar access, while other land uses have limited or minimal off-site shadow impacts. These factors can readily be incorporated into new development controls.

## 5.2 Ontario Regulations

Municipal planners in Ontario have several tools available in shaping development to accommodate solar systems. These range from the general, such as Official Plans, to development area controls, such as zoning by-laws, subdivision plans and agreements, to the site-specific, such as site plan controls, easements, and covenants among property owners. They can also use any number of advisory tools to influence development, such as development review, publications and directives on urban design principles, technical and economic advice, cost-benefit analyses, etc. The latter have informational value for applicants, but no legal status.

Each tool has an important, but limited role in the development approval process, and should be combined with other instruments in order to realize desired community objectives.

## 5.2 (a) Official Plan

The Official Plan includes general policy statements regarding community development goals. It applies to all public works undertaken in the community (many of which can make use of solar systems) and in this sense, could be quite influential in demonstrating the use of solar systems. Solar access, shadow impacts, and similar factors can be introduced in general policies regarding energy conservation in the community.

Given their general nature, Official Plan statements can apply equally to existing areas and new developments, (while recognizing that their scope is necessarily more limited in existing neighbourhoods). General policies are flexible, politically acceptable, and adaptable to changing circumstances, but lack precision in defining solar access and its attributes. Therefore, other more detailed mechanisms must be used in conjunction with the Official Plan.

## 5.2 (b) Zoning By-Laws

A zoning by-law implements Official Plan policies on an area or zonal basis. It is possible, for example, to define land uses requiring solar access, putting parameters on the definition of solar access, and define setbacks, height limits, structural envelopes, etc. within which building is permitted.

Vegetation (existing or new) cannot be controlled in a zoning by-law, yet may compromise the utilization of solar energy by an individual land owner. Also, the zoning by-law does not absolutely guarantee solar access, since it can be changed by legislative action or Committee of Adjustment variances, and is not binding on land title.

Zoning by-laws for existing neighbourhoods may be difficult to modify for solar access due to the concerns of existing residents, but in principle, should be easily introduced in new subdivisions. While readily understood by municipal politicians and community residents, zoning by-laws lack flexibility if building envelopes are defined too rigidly. Solar access can be precisely defined in a zoning by-law, yet how it is to be achieved should be measured rather than prescribed in advance, so as not to inhibit innovation on the part of development applicants.

## 5.2 (c) Subdivision Approvals and Agreements

Subdivision approvals and agreements, by definition, apply only to new development areas. Municipalities have extensive powers to control subdivision layout, and agreements made with land owners can be registered on title, ensuring permanence.

Street and lot layouts can be optimized for solar access at the request of the municipality, and in principle, any agreement or contract can encourage other principles such as minimum levels of energy conservation, or use of solar potential in new buildings.

Solar access to buildings is ensured by road and lot layouts, but the subsequent utilization of solar energy in buildings may be more difficult to control. Rather, subdivision agreements should be seen as frameworks within which solar systems can be made to be physically feasible. This mechanism allows another means besides the zoning by-law for implementing municipal goals, but lacks precision in the definition of solar access, and lacks universal applicability, since it must be repeated in each new development area. In this respect, it may be useful, as well as evolutionary, because subdivision agreements can be altered for subsequent developments, based on experience.

### 5.2 (d) Site Plan Control

Site plan control is a useful mechanism because it allows a municipality to implement another level of development control without altering existing zoning by-laws. It is equally applicable to new and existing development areas.

A municipality can define zones to which site plan control will apply, controlling the location of buildings, structures, and landscaping on the site. Certain uses such as shopping centres and light industrial can be excluded from solar criteria. Although certain physical parameters such as the height and bulk of buildings must still be controlled under the zoning by-law, shadow impacts and solar access could be specified indirectly, within those physical limits.

The administration of site plan control to include solar access criteria could be adaptable and flexible, but is a potentially lengthy process, depending on individual circumstances. It has the advantage of working within existing development potential. The definition of solar access is incomplete and must be used in conjunction with physical criteria specified in the zoning by-law. As a mechanism, site plan controls are readily adaptable to changes in solar criteria and technology, provided that these can be defined by the municipality for the information of development proponents.

### 5.2 (e) Easements Between Adjacent Property Owners

An easement is a private agreement between landowners: an acquisition by the owner requiring solar access, of a right which prevents neighbouring owners from blocking sunlight. An easement is permanent and binding on land title, unless changed by mutual consent.

Since an easement must be expressly created by the owner of the restricted land, who gives up some development rights thereby, it is not likely to become a common mechanism unless he can be given a comparable benefit. By contrast, mutually beneficial easements such as shared driveways are common.

Easements can be precise in defining the access to sunlight, and do not involve political or administrative costs. They would have to be repeated again and again among individual owners to have a substantial effect on a neighbourhood. However, having paid for the privilege of guaranteed solar access, landowners are likely to implement the retrofit changes to their structures in order to utilize the benefits.

Easements need not be used in new development areas, where other mechanisms are available.

### 5.2 (f) Covenants

Covenants restrict an owner's use of his land for the benefit of his neighbours. They are common in new subdivisions, and could be tailored to protect access to sunlight in a precise and permanent manner, binding on title. This very precision, though, would be outside municipal control, and might impose a strait jacket on future redevelopment.

Covenants are feasible mechanisms in new "solar" subdivisions because all incoming owners are treated equally, and receive similar benefits with accompanying restrictions. Even in these circumstances, solar access would have to be defined in a simple and unambiguous manner, so that owners are aware of what benefits they are receiving in their own houses, and the purpose and extent of the restrictions. It is unlikely that a similar commonality of interest could be created in existing neighbourhoods, since many structures would not be suitable for solar retrofit, and their owners would probably not agree to a covenant from which they would not benefit.

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